NATIONAL SCIENCE FOUNDATION

PROJECT SUMMARY

FOR NSF USE ONLY			
DIRECTORATE/DIVISION	PROGRAM OR SECTION	PROPOSAL NO.	F.Y.

NAME OF INSTITUTION (INCLUDE BRANCH/CAMPUS AND SCHOOL OR DIVISION)

University of Utah
Colleges of Engineering and Education
Departments of Bioengineering and Educational Studies, 2480 MEB
Salt Lake City, Utah 84112

ADDRESS (INCLUDE DEPARTMENT)

Department of Bioengineering
2480 MEB
University of Utah
Salt Lake City, Utah 84112

PRINCIPAL INVESTIGATOR(S)

J.D. Andrade, T. Stoddart, J. Gess-Newsome

TITLE OF PROJECT

Science in the Dark: Integrated Science Education Materials Based on Bioluminescence

TECHNICAL ABSTRACT (LIMIT TO 22 PICA OR 18 ELITE TYPEWRITTEN LINES)

We propose to develop, test, and disseminate integrated science "discov materials based on bioluminescence -- light generated by living systems.

This project will develop integrated science materials which involve st centered and parallel teacher education activities, allowing teachers to deve new scientific concepts and a practical understanding of science via the observation of bioluminescence.

The project involves science and teacher education professionals, interdisciplinary scientists knowledgeable in bioluminescence, and a team of practicing elementary teachers. The project includes the development of nove materials and curriculum aids for grades 4-6 *and* means for teacher motivation education. A local company, Protein Solutions, Inc., will scale up the produ and dissemination of the materials. Teacher and student participants will be local school districts and from Northern Illinois via a cooperation with R. Stofflett at Northern Illinois University. A novel means of encouraging dire parent/guardian participation is also proposed.

Preliminary work includes a series of inservice courses, workshops, and classroom testing of the first key module, NIGHT-LIFE.™

This proposal is a resubmission. The concerns of the previous review pa have all been addressed in this revised application.

Scientific discipline(s) involved: Biology, Chemistry, Physics, Life Science, Physical Sci Environmental Science.

Program(s) to which submitted: Materials Development.

Instructional grade levels (within K-12): 4-6

Budget Justification:

Senior Personnel. The amount of work proposed is relatively large in comparison to the personnel cost budgeted. This is in part because the University's new Center for Integrated Science Education (CISE) will provide some resources to assist with the work needed on this project. Dr. Andrade is Director of CISE and Drs. Stoddart, Gess-Newsome, and Winters are all involved. There is a brief discussion of CISE on the next page. Dr. S. Rudolph, Department of Physics, is also a key participant.

In addition, Dr. Andrade will be on sabbatical leave for the 1991-'92 academic year and will be in residence at the University of Utah during most of that period, directing most of his activities to integrated science education, the conduct of this project, and the establishment of CISE (see letter on page after next).

A half-time technician is budgeted, whose activities will be focused on the development of the bioluminescent materials; part-time graduate and undergraduate students will work both on the technical aspects as well as on the teacher and student assessment parts of the project.

We have estimated a 5% annual increase in salaries in the budgets for years two -- through five.

Equipment costs in the first year are for a CamCorder VCR to facilitate the teacher and student interview and assessment process. Incubators are to permit the large scale culture of the bioluminescent microalgae. The office computer will be used for all project related activities, including data storage, analysis, correspondence and related word processing, and the preparation of the educational materials and modules. As virtually all of the materials required for the teacher and student assessment and discovery parts of the project for the first five years will be provided by project funds, it is imperative that a highly efficient and productive mechanism of producing the organisms, related materials, and documents be in place.

The University of Utah is cost sharing on a one for two basis for the equipment items.

The $2,500 budgeted for travel in the first year, and increasing in years 2-3, are in large part for the information acquisition and dissemination activities, some of which are summarized in Table 3 in the proposal. We feel it is imperative that the project professional staff be involved with most major professional meetings in which elementary and integrated science education topics are discussed and presented. The funds used for project related travel will actually be significantly greater than listed in the proposal as Dr. Gess-Newsome will use some faculty start-up funds; Drs. Andrade and Stoddart will also use funds available through CISE and Departmental and College sources.

Materials and supplies are budgeted at $7,500. Most of these funds are for the technical materials.

Publication page charges are budgeted to facilitate the dissemination process through the normal professional journal literature.

Consultant services are budgeted for Dr. Rene Stofflett, one of our collaborators, who is at Northern Illinois University, and will conduct portions of the project in that environment. The other consultant funds are for our advisors listed in Table 2. We anticipate paying our consultants $200 to $500 per day for the days in which they are directly involved with project work. Many of these individuals will be invited to campus to give lectures and seminars in collaboration with the appropriate departments and with the Center for Integrated Science Education, thus the costs of their visits will be spread over these various areas. The amount budgeted ($7,500) is therefore less than the full costs. Teacher consultants are $35 per teacher per half day. We expect to involve 20 to 30 teachers, and have about five half day sessions per year.

Summary. We hope that it is clear that we have proposed a project which is extremely cost effective in terms of NSF funds and support. A budget for five years has been proposed.

The Center for Integrated Science Education (CISE)

The University of Utah has established a Center for Integrated Science Education (CISE). The Center will complement and coordinate existing science education activities and will develop materials and methods by which to teach science in a fully integrated, highly inter- and multi-disciplinary way.

J. Andrade, Director of CISE, argues that there is a revolution developing in science education, particularly at the elementary and high school levels. There is a growing feeling that science should be taught as an integrated discipline, rather than in the highly piecemeal fashion of biology, chemistry, physics, and mathematics, which is the norm today. He and his co-workers feel strongly that the major problem with science education in the United States is that many elementary school teachers, jr. high teachers, and even high school teachers either have a strong and fundamental fear and anxiety about science, or their science skills are in one of the classical disciplines, which therefore makes them unable, or ineffective, in teaching science as an integrated subject, and often makes them unable to relate their discipline to other disciplines and to the students' personal experiences.

The problem is in large part due to the way universities are organized, i.e. in *departments* of chemistry, physics, mathematics, biology, etc. The Center's fundamental argument is that teachers must have an integrated and coherent view of *science*. Project 2061 of the American Association for the Advancement of Science and other reports have argued for the need for a totally new approach to science and mathematics in our public schools.

The Center's objectives are to develop courses, materials, laboratory experiences, and a variety of inquiry and discovery -based modes with which to educate an entirely new generation of teachers, and with which to provide in-service and other education activities for existing teachers.

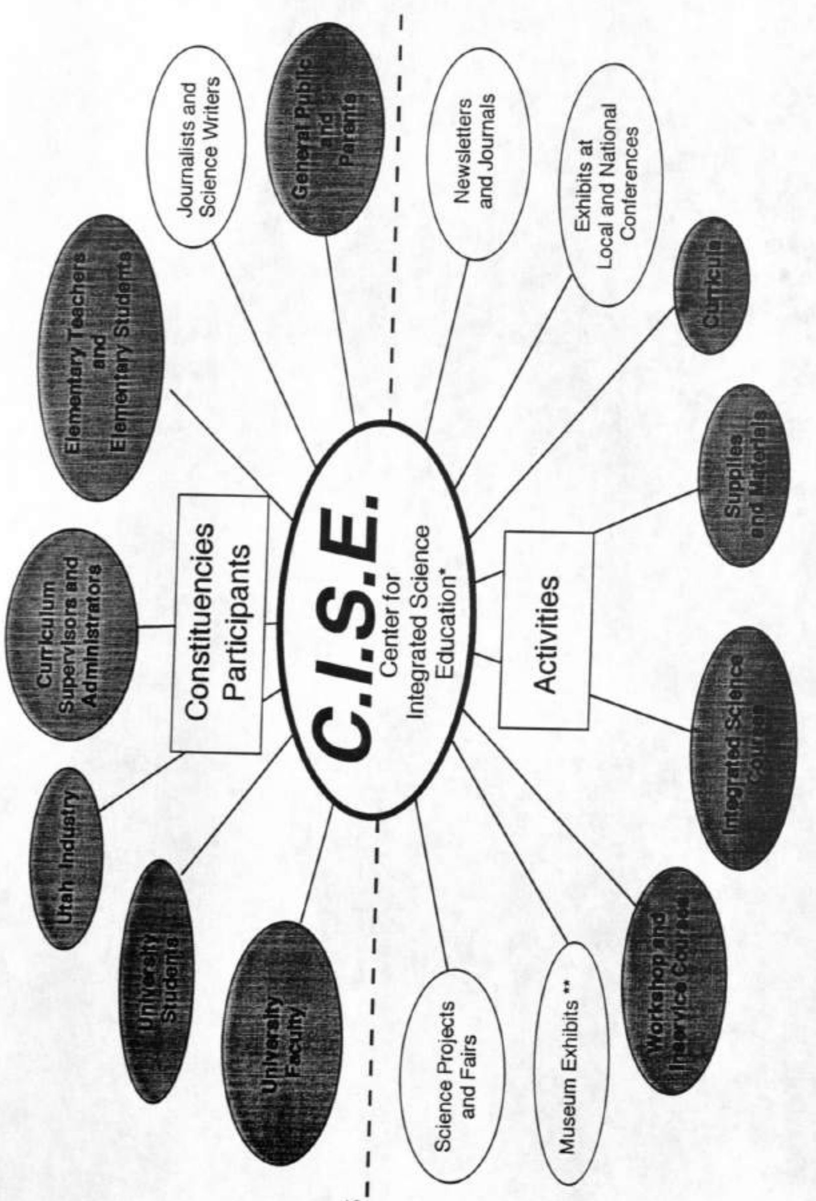
The Center will strive to involve all faculty who have a strong interest and motivation to improve and enhance science education, especially faculty in the College of Science, the School of Education, and the College of Engineering.

There are a large number of faculty who are outstanding science teachers and who have a genuine interest in improving science education. The Center will serve as a focus, a catalyst, a vehicle to integrate and encourage science education activities throughout the campus and the community. Science curriculum coordinators, science teachers, and elementary teachers will be encouraged to become involved in the Center.

In addition, the Center has argued that there is a new industry evolving along these lines, now that the nation has indeed recognized that science teaching must be made integrated and made far more coherent.

CISE occupies over 2,000 square feet of space in the University of Utah Research Park (adjacent to campus), at 390 Wakara Way, Salt Lake City. This space consists of offices and labs, as well as conference rooms and classrooms.

The graphic on the next page shows CISE's constituencies and activities. Those area directly related to this project are shaded.



*Contact J. Andrade, University of Utah, 801-581-4379 for more information.

** With the Children's Museum of Utah and the Utah Museum of Natural History.

THE UNIVERSITY OF UTAH

November 11, 1991

National Science Foundation
Directorate for Science and Engineering Education
1800 G Street, N.W.
Washington, D.C. 20550

Sir/Madam:

It is my pleasure to endorse the proposal, Science in the Dark: Integrated Science Education Materials Based On Bioluminescence, submitted to the Materials Development, Research, and Informal Science Education Program by Dr. Joe Andrade, Professor and Chairman of the Department of Bioengineering in our College.

Dr. Andrade is co-principle investigator with Dr. Trish Stoddart, Department of Educational Studies. Joe has strong interests and activities in the area of science education. In addition to his talents and experience at teaching science and engineering at the college level, he has had some experience in elementary science instruction at the fourth through sixth grade level, and helped work his way through graduate school in Denver by teaching high school general science, biology and chemistry. He is a dynamic inter- and multi-disciplinarian who feels that science should be taught as an integrated subject and who recognized that we must make science education more attractive and exciting if we are to attract sufficient students for the year 2000 and beyond.

Within the last several years he and his group have been researching bioluminescence and it has become clear that this is a phenomenon which can be effectively used to interest and motivate students, and through which an integrated science curriculum can be developed.

Although Joe is continuing to manage an active research program and is one of the most outstanding researchers in my College, he has chosen to devote an increasing percentage of his time to the area of integrated science education. I enthusiastically support his endeavor. The integration of biology, chemistry, physics, mathematics, and technology are really all part of the scope of our Department of Bioengineering, probably the most inter- and multi- disciplinary activity on our campus. The area of integrated education, in my opinion, easily falls within the scope of this Department.

I am pleased to confirm that the University and the College will provide a match to this N.S.F. application in the form of a significant proportion of Joe Andrade's time and effort. Joe is on sabbatical leave during the 1991-'92 academic year and will devote a major part of his time to the project.

Sincerely,

David W. Pershing

D. Pershing, Dean
College of Engineering

mm/n8

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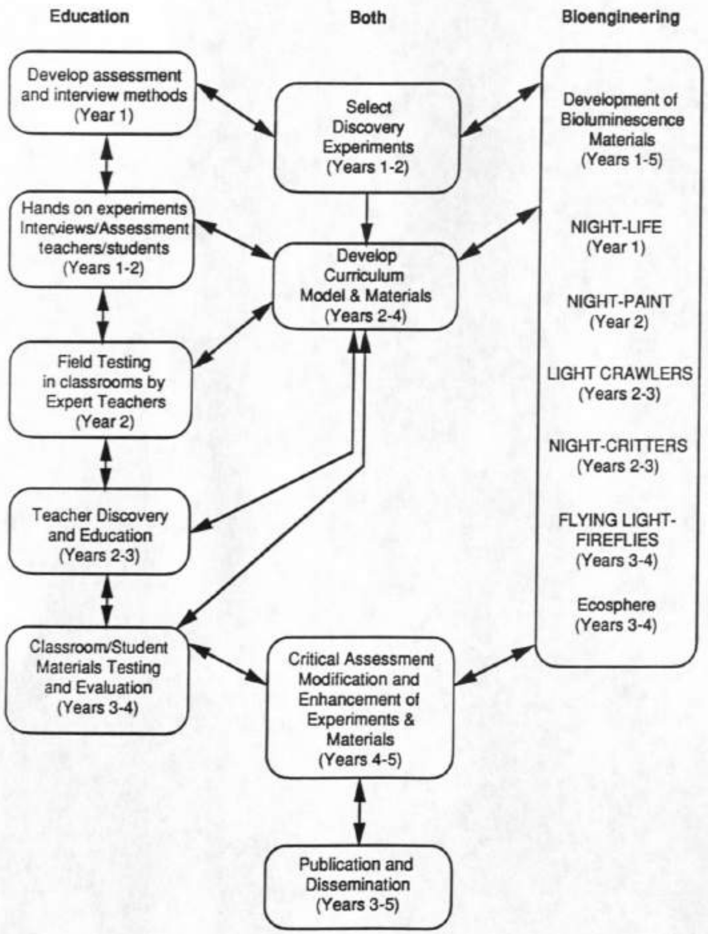

Figure 2. The major subprojects in this proposal.
The right side refers to the research and development aspects (headed by Andrade); the left side refers to student and teacher assessment and education (headed by Gess-Newsome and Stoddart); both groups will be closely involved in the selection and development of experiments and materials (center). The double arrows (⟷) refer to the continual improvement of each subproject based on experience and input from the other. The duration of each subproject is indicated.

Project Description

Objectives:

We propose to develop, test, and disseminate Science in the Dark, an integrated science "discovery" curriculum based on bioluminescence -- light generated by living systems [1,2] (References are on page 30).

Nearly everyone who discovers and observes bioluminescence is impressed and motivated to see and learn more. In these times where children have their senses constantly stimulated to near exhaustion, bioluminescence is a relatively unknown, unexperienced phenomenon which can readily compete for a student's attention and interest.

This project will develop integrated science materials which involve student-centered and parallel teacher education activities, allowing teachers to develop new scientific concepts and a practical understanding of science via the observation of bioluminescence.

The basic idea is to have the students *discover* something completely new -- and then participate in group and class discussions that lead to the development of scientific reasoning and the formulation of questions, hypotheses, and experiments. The teacher and the materials serve as resources to *aid* student discoveries and education.

The materials will aid in the observation, discovery, and learning of basic concepts in various science fields (Figure 1). Process skill such as these are advocated in national curriculum reforms such as Project 2061. Teachers and their students will develop new and expanded understandings of science concepts in a completely new domain -- bioluminescence. The concepts and understanding derived from bioluminescence are general and applicable to the full range of scientific and technical subjects.

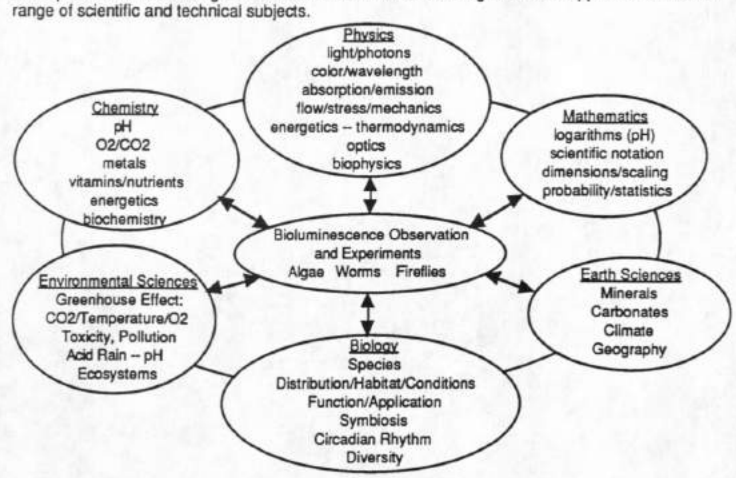

Figure 1: Bioluminescent organisms and their observation are shown as the center of an integrated science "wheel". Each of the classical specialties or disciplines are indicated wit selected subject examples. These subjects and topics can all be directly observed an experimentally studied via bioluminescence.

The project involves science and teacher education professionals,interdisciplinary scientists knowledgeable in bioluminescence and practicing elementary teachers. The project includes the development of novel materials and curriculum aids for grades 4-6 *and* means for teacher motivation and education. There is also a cooperation with a local company which will scale up the production and dissemination of the materials [26,28]. Teacher and student participants will be from the Salt Lake School District, the Davis School District, the Jordan School District, and Northern Illinois University (Table 1).

Table 1: Local Participants and Test & Dissemination Sites

Name:	Affiliations(s):	Location:	Functions:	Phone:
Andrade, JD, PhD	University of Utah, Center for Integrated Science Education (CISE), Dept of Bioengineering	2480 Merril Engr Bldg University of Utah, Salt Lake City, Utah 84112	Principle-Investigator Project Director	(801) 581-4379
Stoddart, T, PhD	University of Utah, CISE and Dept of Educational Studies	307 Milton Bennion Hall University of Utah Salt Lake City, Utah 84112	Co-Principle Investigator	(801) 581-7158
Gess-Newsome, J., Ph.D.	University of Utah, CISE and Dept of Educational Studies	307 Milton Bennion Hall University of Utah Salt Lake City, Utah 84112	Co-Principle Investigator	(801) 581-7158
Winters, S,PhD	University of Utah, CISE and Dept of Bioengineering	2480 Merril Engr Bldg University of Utah, Salt Lake City, Utah 84112	Project Manager	(801) 581-4379
Stofflett, R, PhD	Northern Illinois University, Asst Professor,	Northern Illinois University School of Education De Kalb, Illinois 60115	Consultant & Co-Investigator	((815) 753-9075
Rudolph, S., Ph.D.	University of Utah, Department of Physics	102 JTB University of Utah Salt Lake City, Utah 84112	Co-Investigator	(801) 581-4803
Griffin, Bruce Allred, LaMar	Utah State Office of Education	Utah State Ofc of Education 250 East 500 South Salt Lake City, Utah 84111	Local Advisors	(801)538-7762 (801)538-7791
Steele, David Jensen, LaMont	Research & Evaluation Director Science Coordinator Davis County School District	Davis County School District 45 East State Farmington, Utah 84025	Local Advisors	(801)451-1129 (801)451-1108
Powell, Ken	Curriculum Director Salt Lake County School District	Salt Lake County School District 440 E 1st So, Suite 208 SLC, Utah 84111-1898	Local Advisor	(801)328-7297
Chamberlain, Von Del	Director, Hansen Planetarium; Task Force for a Utah Science Education Center	Hansen Planetarium 15 South State Salt Lake City, Utah 84111	Local Advisor	(801)538-2104 ext. 227
Morris, Richard	Director, The Children's Museum of Utah	The Children's Museum of Utah 840 North 300 West Salt Lake City, Utah 84103	Local Advisor	(801)328-3383
Wollam, Jean	Jordan School District, Curriculum Department	9361 South 300 East Sandy, Utah 84070	Local Advisor	(801) 565-7100 ext. 309
Hague, Don DeCourten, Frank	Utah Museum of Natural History	Utah Museum of Natural Hist. University if Utah Salt Lake City, Utah 84112	Local Advisors	(801) 581-6927

We will develop and produce four different bioluminescent systems (each based on a different organism), develop materials and experiments, use these to assess student preconceptions and interest levels, and use them to assess teacher preconceptions and interest levels. We will then develop modified and enhanced materials. A detailed assessment plan is proposed -- and a comprehensive plan for publication and dissemination. The various sub-projects and task outlines are given in Figure 2.

The "mapping" and relation of the Science in the Dark curriculum supplements to the Utah State Curriculum, Grades 4-6, is given in Figure 3. We are examining other 4-6 curricula, including the Grades 6-8 recommendations of Scope, Sequence, and Coordination (SSC) Project of the National Science Teachers Association (NSTA) [24]. It must be recognized that state curriculums only establish the minimum guidelines upon which local school districts are expected to elaborate. For example, Table 2 lists the topics related to bioluminescence in the Granite School District elementary science curriculum, a list significantly richer than that provided by the State. This table vividly shows how the topic of bioluminescnce can act as a vehicle for the delivery of many of the elementary content objectives in an integrated format. The topics which are related to bioluminescence have been starred. In addition, our bioluminescent activities can act as a point of departure for the further development of the State and district topics.

Background and Rationale -- Bioluminescence:

Those who have observed and experienced bioluminescence generally never forget it. Fireflies on a dark summer night, glow worms or millipedes on a dark path, bioluminescent algae in a dark sheltered bay or on the surface of the sea, or the light emanating from disturbed marine crustaceans in tide pools on a dark night [1-6].

In our present age of intense artificial lighting, video games, and environmental problems, most of the population has not observed bioluminescence. When they first experience it they are generally amazed and almost awestruck -- it seems to be magic.

Bioluminescence is a relatively common and yet largely unknown phenomenon. It has developed and evolved many times. At least seven different independent systems are known and reasonably well characterized [4]. The major functions of bioluminescence are for sexual displays/mating and for predator aversion in the dark. Its only major commercial or economic application at present is as a label or detection aid in diagnostic and clinical chemistry laboratories [5].

We have been studying and working with bioluminescence for four years [7]. When we first discovered and observed it, we, too, became fascinated and "hooked." We have used every opportunity to demonstrate and explain the phenomenon to colleagues, co-workers, friends, family, and children. We have painted ourselves with it for the benefit of infants and preschoolers on dark nights, and we have demonstrated it at numerous dinners, cocktail parties and meetings, for its novelty and conversation enhancement characteristics. We have demonstrated and presented it to preschoolers and to high schoolers, to college undergrads and to engineering graduate students, always with the same effect: an intense interest, awe, and curiosity and a genuine desire to learn more.

Our long range aim is simply to develop and produce integrated science teaching materials based on bioluminescence. Society's problems are not mono-disciplinary, and there is no need for science to be taught in a separated mono-disciplinary fashion. Students know that the physical and biological worlds are indeed interrelated. If we can build on their innate creativity and their natural curiosity and help them see how all phenomena are interrelated and coupled, then we think they will find their school experience, their teachers, and their studies far more credible and interesting. Depending on the observations and the questions, students and teachers can probe into biology, chemistry, physics, mathematics, earth sciences, and environmental sciences [Figure 1]. The approach is to teach by discovery and observation. Discovery and process skills encourage students to develop problem solving strategies that build

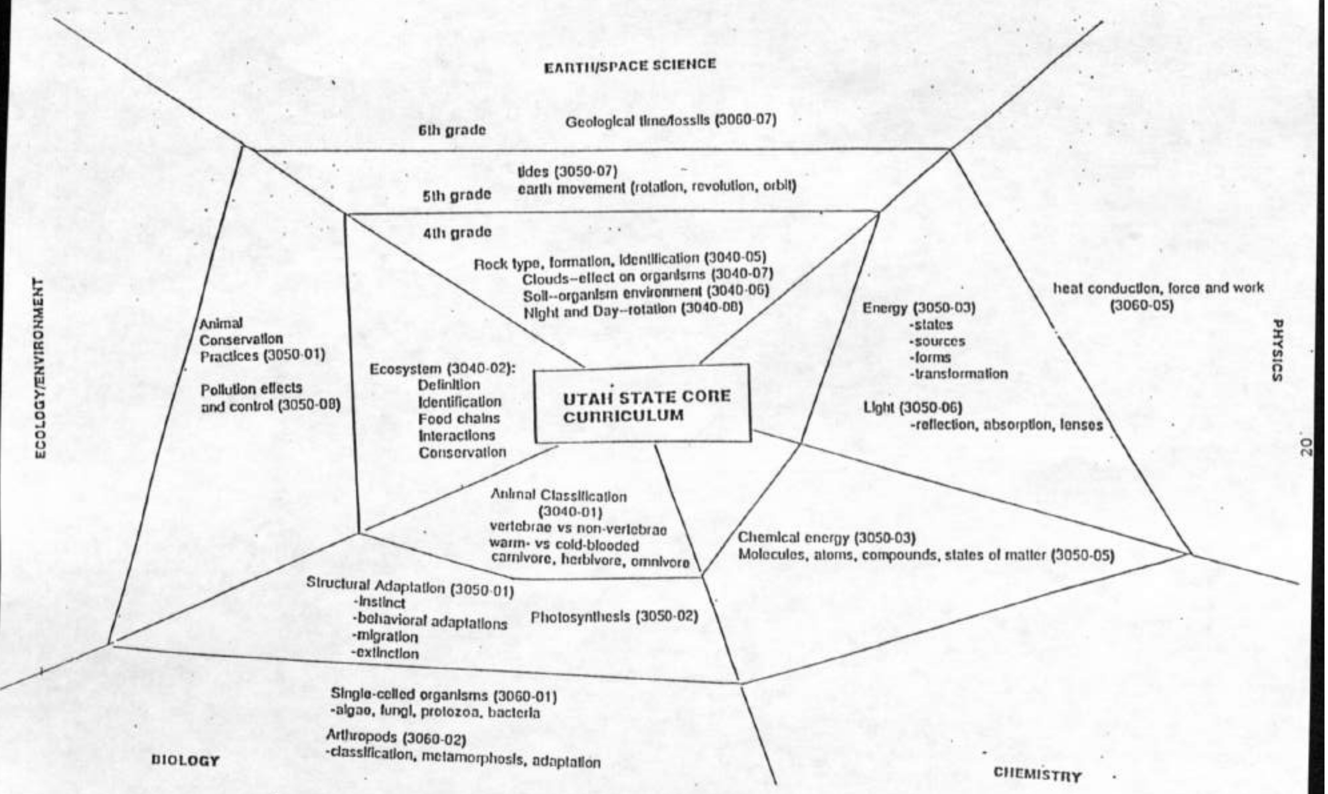

Figure 3. State of Utah core curriculum topics relevant to bioluminescence.

	Lifes Science		Physical Science		Earth Science	
Grade 4	**Animals** • Adaptation • Classification • Endangered species • Basic needs	**Ecosystems** • Plant/animal interaction and interdependence • Limiting factors in nature • Conservation • Environmental adaptations • Heredity	**Sound** Create sound Sound waves Environmental problems Sound differs in pitch, loudness, and quality Sound production (human and other animals)	**Electricity** Simple circuits Conductors/Insulators Current/Static Production/Transmission/Use/Safety	**Rocks** Classify 3 groups Formation/Hardness Fossils Limestone identification Earth's 3 layers **Weather** Cloud types Water cycle Weather conditions Weather prediction	**Soil** • Types and composition Water retention • Soil productivity Topsoil and subsoil • Conservation /Erosion **Solar System** Planets sizes/Motion/Positions Stars Characteristics of Earth Satellites
Grade 5	**Animals** • Structural adaptations • Behavioral adaptations Hibernation Migration • environmental changes • Animal conservation	**Plants** Flowers/Seeds/ Fruit • Structural adaptations Pollination Fertilization • Classification • Photosynthesis	**Energy** Kinetic and potential Sources and forms Stored energy **Electricity/ Magnetism** Electric currents Electromagnets Magnetic compass Magnet characteristics	**Light** • Opaque, transparent, translucent • Concave and convex lenses **Chemical Reactions, Gravity and Heat** Protons, neutrons, electrons • Atoms, elements, compounds, mixtures	**Astronomy** • Rotation Orbits Phases of the moon Eclipses Satellites	**Ecology** • Renewable and non-renewable resources • Pollution
Grade 6	**Microbiology** • One celled organisms • Bacteria and viruses Diseases • Cellular structure **Botany/Zoology** • Plant classification • Photosynthesis Dichotomous keys • Food chains • Patterns of inheritance	**Arthropods** • Characteristics • Classification • Metamorphosis • Adaptability	**Matter and Energy** • Thermometers Gases changed to liquids Heat energy Conduction, convection and radiation Conversion of matter to energy • Periodic chart Nuclear energy		**Meteorology** Air pressure Weather **Space** Jet vs. rocket engines Action-reaction Satellites Astronauts Technology Light years Constellations	**Geology** Crust, mantle, core Geological eras Natural phenomenon • Fossils • Rocks and minerals

Table 2. Granite District Science Curriculum 4-6
• indicates topic which can be discovered and studied via bioluminescence.

on the resources and expertise of each member of the group. Through this process students will learn to value cultural, social, and intellectual diversity. The curriculum materials will also provide students with concrete experiences in utilizing cooperative strategies which can lead to richer conceptual and process skill understandings as well as end products of greater quality than can be achieved through individual competition.

A major advantage in employing bioluminescence is that it is new and interesting -- and that it is not yet fully understood. Thus students and their teachers will experience science as a living, growing, evolving field of inquiry. They will make observations and generate questions for which there are few "answers" -- thereby learning to understand and appreciate the continued growth and development of science.

Background and Rationale -- Education:

Throughout the past 35 years a series of curriculum reform movements have attempted to upgrade the teaching and learning of science in the public schools. Most of these projects have focused on the development and dissemination of innovative curricula and instructional methods for use in the public schools [8]. Such reforms have focused on the development of "hands on" inquiry-oriented instruction aiming to promote students' conceptual understandings through their active engagement and experimentation with scientific content [9]. Many of these science education reforms, however, have been largely unsuccessful. High school students in the 1980's were less interested and less literate in science than ever before [10].

A main source of the problem is that the innovative curricula developed have not been effectively implemented in the public schools. Previous approaches to reform in science education focused on what students need to know but ignored the needs of the key players -- the teachers who prepare them. It is typically assumed that teachers, if provided with innovative curriculum and instructional methods, will be able to implement them [11]. This, however, has not proved to be the case; despite a substantial investment of time and resources, science teaching remains primarily didactic, dominated by lecture, demonstration, textbook readings and memorization [12,13]. This approach to teaching science does not engage student interest or develop conceptual understandings of subject matter. [14,15].

If new science curricula are to be effectively implemented, research and development projects must not only focus on the development of student conceptions, but also on the development of the teachers' knowledge and skills. An effective science curriculum, therefore, will involve the integration of subject matter knowledge with knowledge about the development of scientific conceptions in both students and teachers.

This project will develop integrated science materials which will involve both student-centered and parallel teacher education activities. The inter-disciplinary team includes a subject matter specialist, a science educator and a teacher educator, practicing elementary teachers. The project is based on six assumptions about student and teacher learning:

1. Learners construct understandings as a consequence of their experiences in the physical and social world.
2. Students' learning of the subject matter is the product of an interaction between what they bring to any learning situation and what they are taught. It is particularly critical to recognize the importance of prior experiences and the influence of varying social and cultural backgrounds.
3. Students' prior knowledge and beliefs powerfully affect the ways in which they make sense of new ideas. Such preconceptions may interfere with the acquisition of scientific information and concepts.
4. Learning involves a process of knowledge construction, reconstruction, and concept change.

5. Teachers are also learners. Their approaches to science instruction are influenced by preconceptions about science content and pedagogy developed through their own learning and teaching experience.
6. Development of a science curriculum must be based on knowledge about both the student and the teacher.

Bioluminescence was selected for three reasons:

1. The topic of bioluminescence is intrinsically interesting. Children and adults are awed by the dramatic light emission which they are unable to explain;
2. The topic involves concepts in biology, physics, chemistry, geology and the social sciences (Figure 1). Bioluminescence shows that science is integrated, rather than the isolated subjects portrayed in typical science curricula;
3. The topic of bioluminescence is relatively unknown by teachers. They have little or no prior knowledge of the subject. They have no "fears" of bioluminescence -- they have never failed a test or course on bioluminescence.

Our materials will allow teachers and studies to develop an understanding of important science concepts and science pedagogy within a novel domain. Inservice courses will provide valuable new science content knowledge, with the influence of prior knowledge being minimized. Teachers will feel less threatened about restructuring their views.

It will be important to point out to these teachers how this curriculum fits into their local curriculum. As an example, Figure 3 shows the Utah State 4-6 grade curriculum topics which are related to bioluminescence; Table 2 shows the Granite School District curriculum.

Our emphasis and focus is on the development of *materials*. The materials will permit inquiry and discovery-based activities for teachers and students. Concept and understanding assessment will take place before and after the bioluminescent discovery activities. Such teacher and student-derived information will be used to modify and enhance the materials, which will then be more widely tested and evaluated (see Figure 2).

Work Plans (refer to Figure 2):

Development of Bioluminescence - General:

We have been studying bioluminescence for about 4 years, supported by a small contract from a local company, Protein Solutions, Inc. (PSI). PSI is interested in developing bioluminescent-based education products and children's toys and novelties [26].

This grant will provide materials for the field testing of the curriculum and its application in Years 1-5. It is anticipated that by the end of the grant that classroom quantities of these materials will be available at costs in line with elementary school budgets. The University of Utah has a Technology Transfer agreement with PSI. Both the University and PSI are committed to providing these materials at costs appropriate to elementary and middle school budgets.

We will concentrate on four organisms:

1) Bioluminescent algae or plankton (NIGHT-LIFE). The phyto/photoplankton, responsible for bioluminescent bays and seas, are easy to grow and maintain [26]. They require no facilities or training [26]. They are an ideal means by which to introduce the concepts of cells, cell division, photosynthesis, pH, acid-base, minerals, vitamins, growth rates, and doubling times.

Bioluminescence from these organisms can be mechanically stimulated by gentle agitation. Loud noises will also result in light emission. One of the initial discovery modules may involve students/teachers "talking" to the bioluminescent organisms! The sound waves can actually elicit light emission (are the creatures communicating?!)

Most of these organisms exhibit circadian rhythms --- their bioluminescence is 100 times more intense at night than in the day. Such observations will lead to discussion of biological rhythms and "clocks" (we will reset their "clocks" so they are bioluminescent during normal school hours).

We already have access to NIGHT-COLONY and NIGHT-LIFE, prototype science education kits using bioluminescent plankton[25,26].

2) Crustaceans of the vargula family are readily found in the Caribbean, the coasts of Florida, the southern coast of California, Japan, and other regions. These contain a totally different type of bioluminescence than the plankton. The biochemical system in these crustaceans is very stable and can be stored in dry powder form for indefinite periods. This system will be used in powder and ink form and for its novelty and attention getting characteristics, as well as a teaching tool (NIGHT PAINT, Figure 2).

Our industrial collaborator, Protein Solutions, Inc., (PSI), is developing means to maintain and multiply these and related organisms in aquarium cultures, thereby providing a convenient source without the need to collect from natural populations (SEA CRITTERS, Figure 2).

3) Fireflies. Bioluminescence is widely represented in the beetle families, including the North American firefly commonly seen in the eastern United States in the summer. Live fireflies are collected and maintained in Japan where they are sold and released once a year in a firefly festival, sort of a living biological version of fireworks. We have already talked with Japanese and United States firefly experts and feel that is possible to accomplish the same in the United States. This is an important goal, because the motivational factor involved in the observation of flying light is even more impressive than swimming light. Fireflies are found in Utah and Colorado; we will obtain fireflies from the Utah Lake region, about 40 minutes from Salt Lake City. Together with PSI and the Children's Museum of Utah we are developing means to rear and multiply fireflies in culture. The Museum plans to have a Firefly Room, in which students will observe and interact with FLYING LIGHT (Figure 2).

Firefly bioluminescence is used as an entree and serves as a vehicle to connect to and expand upon many very important topics, including energy in biology.

4. Worms. There are many bioluminescence earthworms [16-18], particularly in the southern and semitropical regions. At least two species are found throughout most of the world. A terrestrial one goes by the scientific name Microscolex phosphoreus; a common marine worm lives at the high tide line and is called Pontodrilus bermudensis[18]. Both are readily collected and maintained and exude a bioluminescent fluid when disturbed or agitated.

Although most students and teachers are familiar with earthworms, few realize that many are bioluminescent. It takes a walk on a lawn or along the shore on a very dark night to spot them.

John Wampler, a professor at the University of Georgia, is a national expert on bioluminescent earthworms [16-18]. J. Andrade and J. Wampler discussed the use of bioluminescent earthworms on April 30, 1991 in Athens, Georgia. Dr. Wampler will advise and help us in the development and use of earthworms as LIGHT-CRAWLER educational materials.

We envision a transparent "WORMLAND" container for the terrestrial worm, a geometry similar to the popular Ant Farm educational toy. WORMLAND would be designed so the worms could be observed undisturbed in their natural state. Means to stimulate their bioluminescence would be provided. Imagine the interest level and questioning rate of students observing bioluminescent worms in the dark!

5. Ecosystems. We will work closely with PSI to develop a completely *closed* (no gas or materials transfer) ecosystem containing different bioluminescent organisms [34]. Light and heat will be transferred through the transparent sealed container. We are committed to producing these mini-biosphere very inexpensively.

Although many other bioluminescent systems are available, these four are the most interesting and stimulating, and through them we can represent a significant part of science (Figure 1).

Development of Bioluminescent Materials by Project Scientists -- Specifics:

1. Microalgae: NIGHT-LIFE (Year 1):

a) Complete development of self-contained cultures of the marine algae (dinoflagellates) pyrocystis lunula and p. noctiluca;
b) Map the acid and mechanical stimulation characteristics of these organisms;
c) Demonstrate the light-dark (circadian rhythm) cycles, and the acid, CO_2, and mechanical (flow, turbulence) dependence of their bioluminescence..

2. Vargula: NIGHT-PAINT, SEA-CRITTERS (Years 2-3):

a) Acquire quantities of vargula from No.Carolina Biological Supply (commercial) and J. Morin at UCLA (advisor);
b) Study and develop optimum means of powdering, storing, and reconstituting the material, including use of additional amounts of vargula luciferin;
c) Using available data and experience, map the locations and distribution of vargula worldwide and the conditions required for their existence and growth [5].
d) Develop means to maintain and produce vargula in culture.

3. Fireflies: FLYING LIGHT (Years 3-4):

a) Map the locations and distribution of firefly bioluminescence;
b) Acquire firefly larvae, store and maintain them, and facilitate their development to fireflies [19];
c) Collect mature fireflies, dissect the firefly lanterns and demonstrate the extraction and concentration of the active products;
d) Study the temperature, salt, pH dependence of the bioluminescence. Demonstrate short flash versus long duration behavior and ATP and luciferin concentration aspects;
e) Culture and grow fireflies in captivity in order to develop an inexpensive source of material and to study the organisms' needs for growth and multiplication.

4. Earthworms: LIGHT CRAWLERS (Years 2-3):

a) Work with Wampler and Jamieson to identify, collect, and maintain those bioluminescent earthworms which are the easiest to handle, probably pontodrilus bermudensis (a marine worm) and micro scolex phosphorous (a terrestrial worm) [16-18];
b) Select the brightest individuals which are readily stimulated to bioluminesce;
c) Study temperature, pH, light, and mechanical effects on their growth, maintenance, and bioluminescence;
3) Map the distribution of earthworms nationally and globally.
3) Work with fish bait suppliers to search and find other bioluminescent worms and environments (for example, a large worm used for fish bait in the South is the "Louisiana Pink," which is bioluminescent in its natural environment.

5. Ecospheres (Years 3-4):

a) Develop Bioluminescent Closed Ecosystems containing dinoflagellates, zooplankton, copepods, crustaceans, worms, and shrimp -- all of which are bioluminescent [34].

Relation to 4-6 Curricula and Content:

Figure 3 presented those portions of the 4th-6th grade Utah State Core Curriculum which can be addressed using bioluminescence-based materials and modules. The inner circle in Figure 3 represents 4th grade, the outer is 6th grade, and the middle contains 5th grade topics. The relation of those topics with traditional disciplines is also shown (see also Table 2).

Since bioluminescence is light emission, via chemical processes, we will prepare a module based on living light, to be used in conjunction with one of the many excellent modules on light and energy [22]. The student will discover light without wires, bulbs, batteries, or heat. Why? He/she will examine the water "solution." The light comes from discrete sources -- can we observe them? With a magnifier, the student discovers the dinoflagellates -- the microalgae. Is it producing the light? Where is its "flashlight"?

Now we are into biology. What is this creature? How does it live? Where? What is the light used for? Where does the light energy come from? What does the "animal" (actually, it's a plant) "eat"? How can it eat only air and water? What is photosynthesis?

The idea is to let the questions flow -- prompted mainly by inquiry and observations.

Our goal is to develop modules which address key parts of 4th-6th grade science content, including:

- Light & Energy
- Photosynthesis
- Atoms & Molecules
- O2/CO2/pH
- Night, Day, Tides, Rhythms
- Ecosystems and Biosphere
- Sound
- Soil
- Protists
- Animals
- Diversity
- Pollutions & Ecology

We will analyze the major *existing curricula* [33] and stay abreast of changes and improvements so that the materials developed are useful to the widest possible audience.

In the third year of the project we will work with our Center for Integrated Science Education to develop bioluminescence-based science fair projects and probably a journal/newsletter. The journal would encourage the students, parents, and teachers to submit their observations and analysis for review and possible publication.

Curriculum:

The project will develop integrated science materials to teach key concepts in biology, chemistry, physics, earth science, and environmental sciences via bioluminescence for students and teachers at the 4th to 6th grade levels. In the first stage of the project interviews with students and teachers will be conducted to identify common perceptions held about the phenomena by both groups at the different grade levels.

The student-centered materials will include a series of modules which will involve the use of group collaborative projects, analysis, hypotheses formation, hypothesis testing, and problem solving, using concrete activities that require observation, measurement, hierarchical classification, inference, space/time relationships and cause and effect.

The teacher education component will include a series of activities designed to enhance teachers' science content and pedagogical understandings [23]. These materials will be directly tied to the concepts covered in the elementary curriculum but will be aimed at expanding and enhancing teacher knowledge of fundamental physical and biological concepts beyond the coverage provided for the students.

In order to develop materials about bioluminescence for elementary teachers, it is necessary to determine what the teachers are currently using in their instructional practice, what their conceptions are about science content and effective science pedagogy, and what the teachers perceive as their needs (both for teacher-as-teacher and teacher-as-learner). In particular, efforts will be made to identify barriers and constraints to the implementation of discovery based and process oriented science instruction in the local school culture. These obstacles will be directly addressed in the development of the curriculum materials.

Twenty elementary school teachers will be recruited from local school districts to participate in the research, development, and field testing of the curriculum and instructional materials. This group will be instrumental in identifying current practices, obstacles, and needs in elementary school science teaching. This group will be drawn from culturally diverse, low, and high socio-economic status schools.

We will identify the content teachers are teaching at various grade levels so that we can include information that will help teachers use the materials in an appropriate way. This identification process will be conducted through a document analysis of current lesson plans, observations of and interviews about elementary science teaching, state and district guidelines, and district adopted textbooks. In particular, we will try to identify and disjuncture between what teachers are required to teach and what they are actually teaching [23].

If teachers are to effectively use these curriculum materials in their classrooms, they need to have accurate scientific conceptions themselves. Once teachers' conceptual inadequacies are identified, then corresponding materials can be developed to assist teachers in learning the new content.

Teachers are more likely to accept a curriculum if they feel some ownership over it. A way to achieve this is to first determine what the elementary teachers' perceived needs are for their science teaching and then design the curriculum to meet those needs. Teachers express desires both as educators and as learners. Teachers give many reasons for not teaching science: lack of content preparation, cost of laboratory supplies, lack of time, and lack of interest. Since elementary teachers frequently have very inadequate science knowledge, they frequently avoid teaching science altogether. Our materials will help meet teacher' science teaching needs, thus they will more likely use the materials.

Subjects: The subjects for this study will be practicing elementary teachers from several Utah school districts and from the Northern Illinois area. These teachers will have at least two full years of teaching experience so that their ideas about science teaching have had a chance to develop. The teachers will also have been teaching science on a regular basis during the last two years. The teachers will be selected from a variety of locations in order to balance the curriculum for widespread use. One teacher from each grade level (4th, 5th & 6th) will be selected from each school. We will emphasize schools with high disadvantaged and minority populations.

Document Analysis: The participating teachers will be asked to supply lesson plans and materials they have used over the past two years in their science programs. These lesson plans, together with texts and supporting materials, will be analyzed for content, instructional methods, and types of evaluation. Comparisons will be made between the teachers at the same grade level so that trends can be identified. The results will be used to determine the general structure of the curriculum currently being used by these teachers, along with the pedagogical practices most commonly used. This will help define the type of teacher support that is needed to accompany the materials.

Clinical Interviews: Each teacher will be interviewed in three parts: interview-about-events (bioluminescence content), pedagogical conception interview (including perceived needs), and interview-about-documents [23]. These interviews will help us determine potential problems in teachers' content and pedagogical knowledge and their perceived needs for enhanced science teaching. This will aid in the development of our teacher support materials.

Discovery Experiments (see Figure 2):.

Four different initial discovery experiments will be developed: dry powder (NIGHT PAINT), algae (NIGHT-LIFE) "communication," [23,25] worms (LIGHT CRAWLERS), and fireflies (FLYING LIGHT).

*The **dry powder** experiment:* - Where does the light come from? (no batteries, bulbs, or wires) - Why is the light blue? Can it be green? Red? - Why do you have to wet it? - Why does the light go out? Can you make it come back? - Why does it smell fishy?	*The **worm** experiments:* - Is that a blue liquid? - Where did it come from? - Why does the worm release it? - Does it help him to crawl in the dirt? - Why does he crawl away from his own light?
*The **algae** communication experiment:* - Why do you have to shake it? - Why is it blue? - Why is it moon-shaped? - Where is its flash light? - How does it live? - Where does the light come from? - What's the light for?	*The **firefly** experiment:* - Why does it flash? - Can it see the first flash? How? - Where does the bioluminescence come from? - Can a dead firefly flash? - Why is it yellow? (the other examples were blue).

The responses to these discovery experiments by both teachers and students will aid us in the development of effective bioluminescence materials and experiments with enhanced inquiry and content characteristics (Figure 2).

The elementary student curriculum models will involve collaborative, group methods; the teacher will serve as a discussion leader to probe student thinking and to lead student discussions following the discovery activity.

Some of the materials will be appropriate for home experiments, to facilitate the involvement of parents and family in the inquiry and discovery science learning process. One of the problems with many students is that the home environment is not particularly supportive of academic activities. Small, very inexpensive modules and materials for the home environment will allow the student to share what he/she has discovered and learned in the classroom with family at home, encouraging parent involvement in the student's learning and discovery processes.

The home experiments and demonstrations will be of minimum cost and complexity and will be designed for less than ideal home environments. We frankly feel that the parents will be as equally impressed and excited about the observation of bioluminescence as are their children.

The teachers in our initial discovery, assessment, and development activities will serve to test and evaluate the materials produced. They will then use the materials "solo" in their classrooms, followed by student assessment and critique, which will lead to even more enhanced materials (Figure 2).

Project participants and teacher "experts" will then provide workshop and inservice training for additional teachers.

Initially, the materials will be provided by the project. As the modules and become fully developed and ready for more wide-spread application, they will be produced by a local company, Protein Solutions, Inc., and made available as inexpensively as possible.

Advisory Board (Table 3):

Our Advisory Board consists of educators, teachers, parents, and scientists. The science experts function as advisors and critics to ensure that the materials we develop are as scientifically accurate as possible:

W.G. (Woody) Hastings, Professor of Biology, Harvard University, is internationally recognized for his work on bacteria and dinoflagellate bioluminescence [4]. He and his co-workers have worked out the basic chemistry of dinoflagellate bioluminescence. He has applied these systems for the study of biological circadian rhythms, and is published widely on the subject. His laboratory and work were recently featured in the Public Broadcasting System program, "The Infinite Voyage" in the recently aired segment dealing with biological rhythms, "The Living Clock."

James Morin is Professor of Biology at UCLA in Los Angeles. Dr. Morin is an expert on the small bioluminescent crustaceans, vargula, formerly called cypridina. Professor Morin has discovered and categorized some 50 new species of these organisms in the Caribbean and the Gulf of Mexico, and has observed that one of the major functions of their bioluminescence is for sexual mating displays. His recent, plenary lecture at the 6th International Conference on Bio and Chemiluminescence, "Shedding Light on Shedding Light", included dramatic videotapes of vargula's underwater luminescent activities.

John Buck, National Institute of Health, Bethesda, Maryland, is well known for his work on fireflies. He has worked with fireflies since the mid 1930's.

James Lloyd, University of Florida, Gainesville, is responsible for the most complete and thorough study of firefly species in the United States.

J. Wampler is with the University of Georgia and is an expert on bioluminescent worms.

Our education/curriculum consultants include Lawrence Lowery, Lawrence Hall of Science, Berkeley, Allan Voelker (Northern Illinois University), and Ted Mills, Oklahoma State University.

Dr. Lawrence Lowery, Professor of Science Education in the Department of Mathematics, Science and Technology in the Graduate School of Education, University of California, Berkeley, is Director of the Educational Research and Applications Teacher Credential Program and a Senior Researcher at the Lawrence Hall of Science. Dr. Lowery is an expert in the development of children's scientific concepts and the design of science curriculum and instructional methods. He is principle investigator of Full Option Science System (FOSS), EQUALS in Technology, Science, Education for Rural California (SIRC) and Family Math. He is Co-PI on the bay Area Math Project. He has received many awards including "Science Educator of the Year" in 1989 from the Association of Educators of Teachers of Science (AETS) and the "National Exemplary Project, Science Instruction for Rural California" in 1987 from the U.S. Department of Education.

Dr. Alan Voelker is Professor of Science Education and Chair of the Department of Curriculum and Instruction at Northern Illinois University. His area of expertise is in the development of science curriculum and materials and the relationship between mathematics and science education and industry. He is currently Principle Investigator on the Scientific Literacy Project for the Illinois State Board of Education, which focuses on developing a K through 12 science and mathematics curriculum linked to the needs of business and industry and a Needs Assessment Study for the Museum of Science and Industry in Chicago. He has been involved in several large national studies, including the National Public Affairs Study and the Longitudinal Study of American Youth.

Dr. Ted Mills is Professor of Science and Environmental Education at Oklahoma State. He is the founder and Director of the DIRECT project, a middle school science and mathematics project to prepare outstanding middle school teachers.

Kathlene Spencer is an experienced elementary school teacher and expert in multi-cultural education. She spends 50% of her time as an advisor in multi-cultural education to the Utah State Department of Education and 50% as as an assistant principal in a culturally and socio-economically diverse elementary school. She is enrolled in a doctoral program in Education at the University of Utah and is conducting research on the development o problem solving skills in minority elementary school children. Ms. Spencer is of Afro-american heritage.

Table 3: National Advisory Committees

Lowery, L.	Lawrence Hall of Science, Berkeley
Voelker, A.	Northern Illinois University
Baker, D.	Arizona State University
Mills, T.	Oklahoma State University
Spencer, K.	Salt Lake Elementary School
Hastings, W.G.	Dept of Biology, Harvard Univ., Cambridge MA (bacteria, dinoflagellates)
Morin, J.	Dept of biology, UCLA, Gos Angeles, CA (crustaceans, fish)
Buck, J.	National Institute of Health, Bethesda, MD (fireflies)
Lloyd, J.	Dept of Biology, University of Florida, Gainesville, FL (fireflies)
Wampler, J.	Dept of Biochemistry, University of Georgia, Athens, GA (earthworms)
(to be appointed)	Two elementary teachers
(to be appointed)	Two parents

Project Schedule (refer to Figure 2):

In year one we will develop the assessment and interview methods, perform research and development on the various types and classes of bioluminescence, and select and implement two basic discovery experiments. Given the assessment and interview methods and the discovery experiments, we will then initiate the student and teacher demonstrations and the interview and assessment process. All of this is to be completed in year one.

In year two the development of bioluminescence will continue in order to have available a more complete and appropriate understanding and a wider range of experiments and observations. Given the bioluminescent materials available at that point, and the responses from the interviews, we will then develop preliminary materials. This will be done in close collaboration with our Advisory Board, with local school districts and with our collaborator at No. Illinois University, R. Stofflett.

These activities will require much of the first part of year two. The curriculum model and materials will be available towards the latter part of year two, and will then be field tested in classrooms by expert science teachers, by the Focus Group, and by selected other members of the faculty and of the participating schools.

Given the results of the field testing and the initial model curriculum and materials, we will then initiate appropriate in service training for a selected group of interested teachers. This will be done towards the end of year two and in year three. The group of educated teachers will then introduce the bioluminescence materials to their particular classrooms.

Meanwhile, bioluminescence research and development will continue with better and more enhanced bioluminescent materials and modules being produced.

Towards the middle of year four there will be a critical assessment of the model curriculum, of the materials, and of the results; and we will then modify and enhance the experiments and the materials (years 4-5).

The overall goal is, by the conclusion of year four, that a well tested, integrated partial curriculum, based on bioluminescence, will be available. In addition, we will have learned a great deal about the fundamentals of teacher and student discovery and education in science.

We will publish and disseminate information about this project during the entire five year period (Table 4). At the end of year four even more extensive publication and dissemination activities are planned.

Monitoring and Evaluation

Our Advisory Committee (Table 3) consists of experts and advisors to provide guidance, critique, and input on all phase and aspects of the project.

A set of experts on bioluminescence will review and critique all of the materials and exhibits to minimize any scientific inaccuracies or misinterpretations. Several will be individually invited to campus to give seminars and lectures at the University of Utah on their bioluminescence work and to observe and to assess the activities and developments in this project. We expect them to be active partners throughout the entire project.

Recognized and accomplished science educators will provide criticism and advice regarding the implementation and application of the bioluminescence modules to the student and teacher populations.

Practicing elementary teachers and parents will also monitor, evaluate, and critique.

The full committee will meet every 6 months via conference calls and every 12-18 months in person. Each will prepare a brief written critique and assessment of the project.

Organization and Management

This project is a cooperation between the Department of Bioengineering and the Department of Educational Studies at the University of Utah. Bioengineering is an inherently inter- and multi-disciplinary program, which merges all areas of science, engineering, and medicine. J. Andrade, Professor of Bioengineering, will serve as Principle Investigator and will be responsible for the scientific and technical side of the project (the right side of Figure 2). Working closely with Suzanne Winters, Joe will directly supervise all of the bioluminescence research and development activities, the preparation of materials and experiments, and the scientific and technical evaluation of all written materials.

Drs. Trish Stoddart and Julie Gess-Newsome, Assistant Professors of Educational Studies, are Co-Principle Investigators and will be responsible for the educational studies aspect of the project (left side of Figure 2). They will work with Rene Stofflett from No. Illinois University. All have strong science and science teaching backgrounds. Drs Stoddart, Gess-Newsome, and Stofflett will be responsible for all of the direct education and teaching aspects of the project.

Dr. Suzanne Winters will manage the technical aspects of materials development and will work closely with the other participants in developing suitable materials and modules.

Dr. S. Rudolph will assist Drs. Andrade and Winters in developing modules and methods related to physical science concepts and discoveries.

The group will work closely together on the selection of topics and the design and development of experiments and materials (the central portion of Figure 2).

Utilization & Dissemination (Table 4)

Presentations and progress reports on the Science in the Dark bioluminescence will be presented at regular intervals to the annual conferences of appropriate professional societies. We will strive to obtain input and advice from all appropriate education and science communities.

Table 4: Dissemination Activities 1992-'93

National:	
Association of Teacher Educators	Stoddart
American Association for the Advancement of Science	Andrade
American Education Research Association	Stoddart
Northern Illinois University, Colleges of Education & Science	Stofflett
National Association for Research in Science Teaching	Stofflett
National Science Teachers Association	Andrade
Association for the Education of Science Teachers	Gess-Newsome
Local:	
Center for Integrated Science Education (CISE)	Andrade
Colleges & Schools of Education (University of Utah, Utah State University, Brigham Young University, Weber State University)	Gess-Newsome
Utah Association of Supervisors & Curriculum Development	Gess-Newsome
Utah Education Association	Andrade
Utah Science Teachers Association	Gess-Newsome
Utah Teacher Education Association	Stoddart
Inservice Courses:	All

Cooperative Relationships

During the first five years of this project the materials will be produced on campus. The bioluminescent algae prototype NIGHT-LIFE,™ is already available commercially [26]. The scientific and technical materials will be produced in the laboratories of the Center for Integrated Science Education (CISE). The curriculum will be made available to participating teachers in schools in Utah and in No. Illinois on a gratis basis with the costs covered by project budgets and resources. Inservices will be offered through CISE -- some of the inservice costs are recovered by CISE from the participating schools and districts.

In year four a small set of curricular materials will also be available to others who inquire and appear to have a strong interest in implementing the curriculum.

The bioluminescence concept for science education is being developed in partnership with Protein Solutions, Inc. (PSI), a small Utah company whose goal is to develop bioluminescence-based education products for children [26,28]. PSI has provided the funding and motivation which led to the existing bioluminescence expertise in Dr. Andrade's laboratory.

The University of Utah and PSI have mutually agreed that PSI will produce, market and distribute the materials at costs commensurate with typical elementary school budgets. At the conclusion of this NSF sponsored project, the company would subcontract with the University to maintain, enhance, and expand the bioluminescence integrated science curriculum, Science in the Dark.

We, therefore, have in place a mechanism to develop outstanding materials for science education and a means to distribute and disseminate the curriculum to the widest possible audience, thereby insuring its wide acceptance and implementation.

References, Bibliography, and Notes:

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   P.A.Zahl, "Fishing in the Whirlpool," Nov, 1973, p.579.
   D.L. Teimann, "Nature's Toy Train, The Railroad Worm," July, 1970, p.58.
   P.A. Zahl, "Fireflies," July, 1962, p.48.

2. Several major encyclopedias include articles on bioluminescence:

   Encyclopedia Britannica
   McGraw Hill Encyclopedia of Science and Technology

3. Popular science articles include:

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   P. Huyghe, "Wheels of Light, Sea of Fire," *Oceans*, Dec, 1987, p.21.
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   P.J. Herring, "How to Survive in the Dark: Bioluminescence in the Deep Sea," in M.S. Laverack, ed., *Physiologic Adaptation of Marine Animals*, Soc. of Experimental Biology of Great Britain, *39*(1985)323-351.

4. J.W. Hastings, "Biological Diversity, Chemical Mechanisms, and the Evolutionary Origins of Bioluminescent Systems," *J. Molecular Evolution 19*(1983)309.

5. Although bioluminescence is largely unknown in the K-12 and college curricula, there is an extensive scientific literature:

   E.N. Harvey, *Bioluminescence*, Academic Press, 1952.
   A.K. Campbell, *Chemiluminescence*, VCH Publ.,1988
   F.H. Johnson and Y. Haneda, *Bioluminescence in Progress*, Princeton Univ. Press, 1966.
   P.J. Herring, *Bioluminescence in Action*, Academic Press, 1978.
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6. There is a limited discussion of bioluminescence in science and nature books for children. the most complete is:

   A. and U. Silverstein, *Nature's Living Light*, Little, Brown, & Co., 1988.

7. Our interest in bioluminescence began in 1985 when J. Andrade became interested in the subject and began doing some simple "discovery" experiments. Work began in earnest in the Fall of 1987. Protein Solution, Inc. (PSI) was established in early 1988 with the goal of developing bioluminescence for the children's education and toy markets.

PSI has been funding bioluminescence work in Andrade's lab for nearly 3 years (about $60,000 total to date). It was already clear in 1987 that bioluminescence was a real attention getter and motivator of children and adults. Andrade's wife, Barbara, is a first grade teacher. Together they developed several demonstrations and experiments. The phenomena were presented to Dr. T. Stoddart and R. Stofflett in the Department of Educational Studies. Science curriculum specialists in the State Office of Education, several local school districts, and local educators and students were all excited (Table 2). It was decided that there was sufficient interest and commitment among all involved to prepare a proposal to NSF in order to develop integrated science discovery materials based on bioluminescence.

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18. J.E. Wampler & B.G.M. Jamieson, "Cell Bound Bioluminescence From Pontodrillus Bermudensis," *Ibid, 84A* (1986), pp. 81-87.

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21. T.A. McMahon & J.T. Bonner, *On Size and Life*, Scientific American Library, 1983.

22. National Sciences Resources Center, *Resources for Children*, National Academy Press, 1988.

23. R.T.S. Stofflett, "NIGHT-LIFE: The Development of an Instrument Assessing Teachers' Knowledge of Bioluminescence", paper for Bioengineering 695 -- Independent Study, April, 1991.

24. National Science Teachers Association, "The Content Core: Scope Sequence and Coordination," March, 1991.

25. J.D. Andrade, et at., "NIGHT-COLONY: A Science Discovery Tool," abstract, Pacific Division, Amer. Assoc. Adv. Science (AAAS), Logan, Utah, June 23-27, 1991.

26. Protein Solutions, Inc., first product is NIGHT-LIFE,™ a culture of bioluminescent microalgae which is now being sold locally as a science educational kit. National distribution will begin in early 1992. PSI will provide gratis single copies of NIGHT-LIFE,™ to educators on request, providing the recipient agrees to provide feedback, critique, and suggestions. Simply call PSI at (801) 277-1259 (evenings).

27. We have already assembled an amateur 20 minute videotape on bioluminescence for internal use, involving 2 PBS segments on bioluminescence:

28. Protein Solutions, Inc. has initiated a Bioluminescence Science Club by which its customers and participants can share experimental data and results.

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Biographical Sketches:

Joe Andrade is Professor of Bioengineering, of Materials Science and Engineering, and of Pharmaceutics at the University of Utah and is the former Dean of the College of Engineering (1983-87). Several years ago Joe became increasingly interested in the issue of science education for the general population. He taught a course in the Department of Communications two years ago titled "Critical Science Communication, Separating Fact From Fantasy," which was stimulated by the University of Utah's press release dealing with cold fusion and the public interest which ensued. His interest in the science education of journalists and communications specialists is reflected in this proposal.

While in graduate school Joe taught high school general science, biology, and chemistry in a parochial high school in Denver, where the "Science by Seduction" approach was practiced. Basically, his students had all been expelled from the public schools, and it appeared that the only thing that attracted their attention was sex. That became the underlying theme and concept of the life science and biology course, and he managed to find ways to tie a significant part of a high school biology curriculum to the general theme of sex.

Joe was also is in a cooperative elementary program when his two boys were in elementary school and taught 4-6 grade 6 hours a week for 3 years. His wife, Barbara, is a first grade teacher with some 12 years of teaching experience, and they have worked closely together in developing experiential modules for elementary students based on the phenomena of bioluminescence.

Joe recently decided to devote a significant portion of his time and career to the area of science education. He recently established the Center for Integrated Science Education at the University of Utah, and is working to involve all faculty, staff, and even graduate students on campus with interests in science education. He has begun to give inservice courses to local school districts and is involved with the National Science Teachers Association and its local affiliate, the Utah Science Teachers Association. His bioluminescence inservice courses have been very popular with elementary and middle school teachers. His discoveyr demonstrations with 4-6 grade students are in great demand locally.

He is an accomplished scientist and engineer with 5 books, over 100 peer reviewed papers, and 5 patents. His research group focuses on proteins at interfaces and proteins as engineering machines and devices.

Dr. Julie Gess-Newsome is a science educator with a focus on the science understandings of preservice and inservice elementary teachers. Julie's interests in these topics have been stimulated by her eight years of experience as a high school biology teacher. With this background, she was surprised at the poor quality of the science content courses she completed while working on her Ph.D. studies. This experience raised questions concerning the understandings which students, particularly preservice teachers, derive as a result of college and university science courses. In particular, she is interested in the impact of university science courses on the conceptual understandings which teachers have of science, methods of enhancing these understandings, and the mediating variable which influence the translation of science understanding to classroom practice. She is also studying preservice biology teachers. Her dissertation specifically looks at inservice biology teachers' understanding of content as it influences their classroom practice.

Dr. Trish Stoddart is a cognitive and developmental psychologist with a focus on teacher learning and development ,and teacher education. She is particularly interested in the development of subject-specific pedagogy and has conducted research in the areas of mathematics, science, and writing. As a Senior Researcher with the National Center for Research on Teacher Education, she was involved in a five year study on teachers' subject matter knowledge. She brings to this project her expertise in the development of teachers' content and pedagogical understandings for teaching science. Over the past two years with the assistance of a graduate student, Rene Stofflet, she has investigated the scientific conceptions of elementary

education students and the use of conceptual change pedagogy to improve their science content knowledge. This work will contribute to the development of this project. She has published extensively in the areas of teacher learning and development.

In addition to these major participants, there are a large number of individuals on campus involved and committed to the issue of science education and science literacy. In particular, Dr. Ron Ragsdale, Professor of Chemistry, has developed a new Liberal Education chemistry course for non-chemistry majors titled, Architecture and Behavior of Molecules, emphasizing the understanding of chemical concepts through experiments and demonstrations. Dr. Ragsdale gives a very popular public lecture series each Christmas called the Faraday Christmas Lectures, which instils into the public the excitement of chemistry. Dr. Sid Rudolt, of the Department of Physics, has been very active in inservice and workshop mechanism on physics principles for local teachers. Dr. Tony Eckdale, Professor of Geology, has been involved with Liberal Education courses and Honors Program courses in the area of integrated science, particularly as applied to the earth sciences and ecosystems. Dr. Jack Simons, Distinguished Professor of Chemistry, a theoretical chemist, has been very involved in encouraging and facilitating science experiences for undergraduates. Dr. Richard Stiener, Department of Chemistry, is involved with the American Chemical Society's Division of Chemical Education and in the Development of chemistry courses and experiences for high school students and undergraduates. Dr. Joel Harris, also of Chemistry, has also been involved in experiential based courses for non-science majors. Dr. Hugo Rossi, Dean of the College of Science and Professor of Mathematics, is one of the leaders of the Utah Mathematics Coalition and has been working closely with University and State officials to enhance science education in Utah. Dr. Rossi has also taught an integrated science concepts course with a strong experiential component for advanced freshmen women.

We have talked with many professors in the College of Engineering. For example, Craig Rushforth (Electrical Engineering), Robert Johnson (Computer Science), others in the College of Science, in the Department of Biology, in the College of Pharmacy, the College of Medicine, the College of Earth and Mineral Sciences, and in various departments of the College of Health. There are at least 25 people on this campus alone who will be interested in assisting, advising, and participating in this, and related projects.