THE UNIVERSITY OF UTAH

June 14, 1991

Dr. Barbara Butler
Informal Science Education
National Science Foundation
Room 635
1800 G Street, N.W.
Washington, D.C. 20550

Dear Dr. Butler:

I am pleased to submit a pre-proposal, NIGHT WALK: Science in the Dark Using Bioluminescence, to the Informal Science Education Program of the Directorate for Science and Engineering Education.

This proposal has been under development for nearly one year as a joint collaboration between the Center for Integrated Science Education (CISE) at the University of Utah and The Children's Museum of Utah.

We hope that you, your colleagues, and your advisors find this project responsive and appropriate to the Informal Science Education Program. We look forward to your critique and to the possibility of submitting a more formal proposal for your August 1 deadline.

Please let us know if you need any further information.

Thank you.

Sincerely,

J.D. Andrade, Ph.D.
Professor and Chair

mm/je18

cc: C. Blankenship, Dean, School of Education
D. Pershing, Dean, College of Engineering
R. Morris, The Children's Museum of Utah
S. Winters, Protein Solutions, Inc.

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Preliminary Proposal

NIGHT WALK
Science in the Dark Using Bioluminescence

Submitted by the University of Utah Center for Integrated Science Education
J.D. Andrade, Principle Investigator
(801) 581-4379

We propose to develop, test, exhibit, and disseminate NIGHT WALK, an integrated science "discovery" system based on bioluminescence -- light generated by living systems.

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

Bioluminescence is a phenomenon which is largely unknown to students and teachers and almost totally excluded from all science curricula and textbooks, from kindergarten to undergraduate college. Although fireflies are a common experience in the East and Mid West, they are not normally seen west of the Rocky Mountains.

The project will develop integrated and interactive science exhibits which will be used for public education activities in an informal and interactive setting.

The basic idea is to have the participants *discover* something completely new -- and then encouraged to ask questions and formulate hypotheses. Observation of living light leads immediately to a set of questions:

- 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?
- Why do you have to shake it or poke it?

Depending on age and background, participants will discover their own answers and be led into various areas and aspects of science.The exhibits serve as resources to *aid* their discoveries and education.

Depending on the observations and the questions, visitors can probe into biology, chemistry, physics, mathematics, geology, and environmental sciences (Figure 1). The approach is to teach by discovery and observation -- and let the visitors go where their interests take them. As long as the student remains motivated and in a discovery mood, they will learn science. Our goal is simply to help guide -- to help them discover that science is integrated -- is a coherent whole; that it is non-threatening, fascinating, and fun -- and that they can discover, appreciate, and understand it.

Our long range aim is simply to put together a fully integrated science discovery system based on bioluminescence.

We propose a 3 year collaborative interdisciplinary project to research and produce interactive discovery exhibits. The is a collaborative effort between the University of Utah's Center for Integrated Science Education, The Children's Museum of Utah, and Protein Solutions, Inc., a local company specializing in materials for science education (Figure 1).

The materials will aid in the observation, discovery, and in the learning of basic concepts in various science fields (Figure 2). The visitors 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.

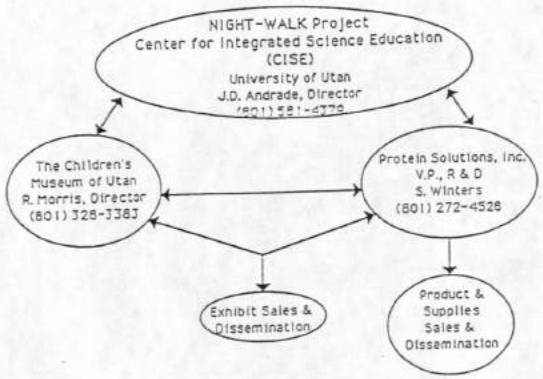


Figure 1. Participants in the NIGHT WALK informal science education project.

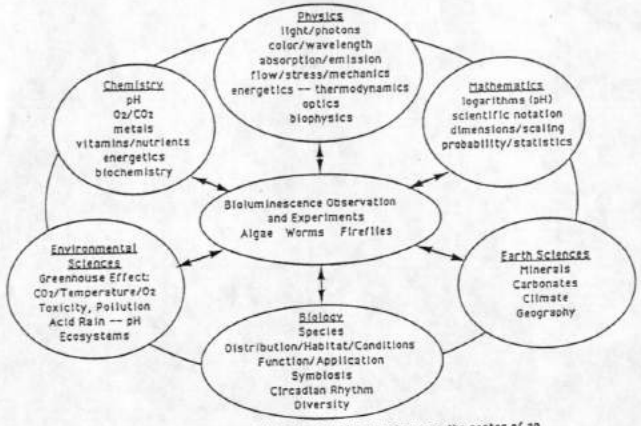


Figure 2: Bioluminescent organisms and their observation are shown as the center of an integrated science "wheel". Each of the classical specialties or disciplines are indicated with selected subject examples. These subjects and topics can all be directly observed and experimentally studied via bioluminescence.

We will develop and produce 5 different bioluminescent exhibits, combine them to produce a comprehensive discovery exhibit, and prepare and provide supplementary discovery materials and kits.

An assessment plan will be included -- as well as a comprehensive plan for publication and dissemination.

Bioluminescence is a nearly ideal phenomenon with which to study the effectiveness of exhibits on visitor motivation and education.

Bioluminescence is not a completely understood phenomenon; much science in the field remains to be done. It is a living, breathing, developing field of science and not an old, established subject. Old, established subject areas tend to be treated didactically; bioluminescence cannot. Educationally and scientifically it must be treated in an observational and experimental manner.

PROJECT PLAN (Figure 3)

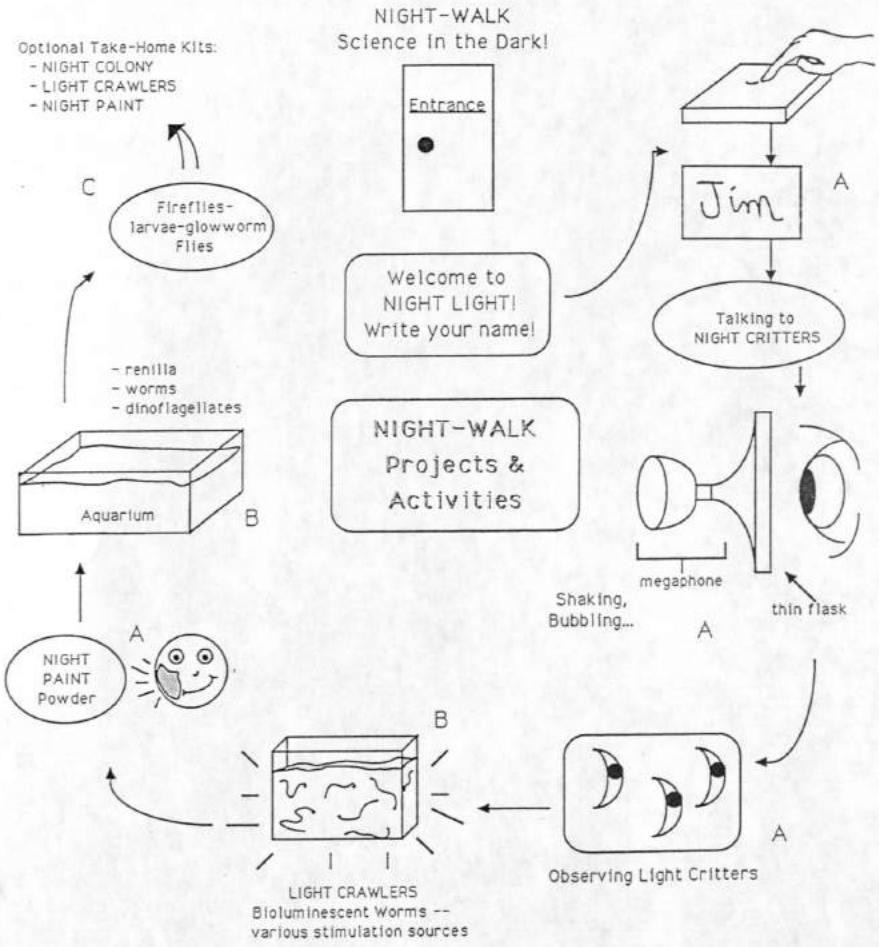
We have available a set of technologies which will make it possible to demonstrate and experiment with bioluminescence in a highly interactive, inquiry-based mode. Cultures of bioluminescent microplankton, dinoflagellates, produce brilliant blue light when mechanically stimulated. We propose to develop means to produce a high viscosity suspension of these organisms using neutral polymer thickening agents. The visitor will then be able to literally write his or her name in the dark by pressing gently on a slightly deformable transparent container. The image will be recorded with a video camera and transferred to a printer, producing a Name Card for the visitor, which he/she will wear during the visit and then take home -- a reminder of his or her activities at the museum.

After this introduction to bioluminescence, which we may call "Night Light," a second module would involve "talking" to the same suspension culture. Since the bioluminescence is produced by a light mechanical disturbance, the stimulation can be produced acoustically. After some gentle tapping experiences, the visitor can talk into a megaphone, which will be coupled to the container so that the acoustic vibrations stimulate the bioluminescence. That will in turn lead to some discussion and additional experiments with intensity and frequency, which will enable the visitor to understand that sound is a mechanical pressure pulsation, which can be transmitted to the culture and directly interacts with the organisms involved.

They will then move to a module where they will do experiments to actually see the organisms responsible for the light emission, the organisms which they have been talking to. This will involve simply placing a small amount of the solution into a 35 mm slide holder and projecting it on the wall. That provides about a 50X magnification. Most of the students are familiar with projectors of some type or other, even if they are not familiar with microscopes. The projector functions as a low power microscope; they see the creatures swimming on the wall. We may also have a microscope module to connect that experience with conventional magnification and microscopes.

Another module would be LIGHT CRAWLERS, an exhibit analogous to the very popular Ant Farm. Instead of ants in soil, there would be earthworms in soil. These earthworms are bioluminescent when mechanically or electrically stimulated. This will lead to a set of interactive experiments dealing with soil, soil humidity and conductivity, and the mechanics of worms in soil; the worms exude their bioluminescence via a mucous slime, whereas the dinoflagellates in the previous experiments generated the light from intracellular granules. The worms will be stimulated by mechanical tapping; we may also use electrical stimulation.

We will then move to an exhibit dealing with a small sea crustacean -- the so called Japanese Firefly. The powder, derived by grinding the dead organism, produces a beautiful, intense bioluminescence. This leads to another activity, a finger-paint activity, in which participants can paint their names, their faces, or whatever -- NIGHT PAINT will also be available for take home and school experiments.



Technologies:

A = Technology in hand.
B = Technology: Year 1
C = Technology: Year 2

Figure 2: Preliminary ideas on a set of bioluminescence-based activity exhibits for interactive science museums.

We then move to another exhibit, which actually is a small marine aquarium in which many of these organisms are located, including jellyfish, marine worms, the same dinoflagellates that they experienced before, and possibly the crustaceans from which the Night Paint was made; they will see all of these organisms in action in the dark.

Finally, we may move into an exhibit dealing with fireflies, starting with the firefly larva, or glowworm, then moving on to freshly transformed fireflies. This is the trickiest part of the process because although firefly larva can be maintained in storage for several years, the fireflies themselves are very delicate and sensitive. However, in an appropriate environment we should be able to transform larva to fireflies indoors. In fact, there is a considerable Japanese experience with this activity.

Schedule: The work would be spread out over three years. In the first year we would take existing technology and transform and develop it into an interactive exhibit format, working closely with The Children's Museum of Utah and the Utah Natural History Museum and their advisors and co-workers. We would also begin the technology development labelled as "C" in Figure 3..

In year two we would conclude the development of the "B" technologies and work on the "C" technologies, that is, the firefly, and try to complete that by the end of year two. By the middle of year two we would expect to have the technology for each of these modules or exhibits in place, and then can begin working closely with professional interactive exhibit designers to put together a formal museum exhibition.

The overall goal, by the conclusion of year three, is to have a well tested, integrated science exhibit, based on bioluminescence. In addition, we will have learned a great deal about the fundamentals of public discovery and education in science.

Dissemination: We will publish and disseminate information about this project during the entire three year period. At the end of year three extensive publication and dissemination activities are planned.

MONITORING AND EVALUATION

Two different Advisory Committees for this project are being formulated:.

A set of experts on bioluminescence will be asked to review and critique all of the materials produced to minimize any scientific inaccuracies or misinterpretations. They will be individually invited to campus to give seminars and lectures 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.

A second group of experts, recognized and accomplished science museum and professional science educators, is also being assembled. These individuals will provide criticism and advice regarding the implementation and application of the bioluminescence modules. They will also participate in critical assessment of the exhibits. At that point they will be augmented by another group, which has had no previous exposure to the project, to provide an objective critique and assessment.

ORGANIZATION AND MANAGEMENT

This project is a cooperation between the Department of Bioengineering, the Center for Integrated Science Education, and the Children's Museum of Utah (Figure 1). Bioengineering is an inherently inter and multi disciplinary program, which merges all areas of science, engineering, and medicine. J. Andrade, Professor and Chairman of the Department of Bioengineering, will serve as principle investigator and will be largely responsible for the scientific and technical side of the project. He 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.

Mr. Richard Morris, Director of The Children's Museum of Utah (Figure 1) will advise regarding exhibit development and implementation.

COOPERATIVE RELATIONSHIPS

During the first three years of this project the materials will be produced on campus. The scientific and technical materials will be produced in Dr. Andrade's laboratories.

The bioluminescence concept for science education is being developed by Protein Solutions, Inc. (PSI), a small Utah company whose goal is to develop bioluminescence-based education products for children. 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 exhibits, in collaboration with the Children's Museum of Utah.

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

BUDGET:

We anticipate requesting a budget of about $125,000/year for three years. Direct costs would average about $84,000/year. About half of the total would be expended for bioluminescence technology and materials development. The other half would be used for exhibit development, testing, evaluation, and dissemination costs. No other funds are available for this project.

FOR FURTHER INFORMATION, CONTACT:

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full proposal

H. PROJECT DESCRIPTION

1. Objectives:

This proposal is specifically aimed at the development, construction, and testing of an exhibit, NIGHT WALK, an integrated science discovery exhibit based on bioluminescence -- light generated by living systems (1-3). Additionally, this proposal addresses the assessment of the exhibit and dissemination of the exhibit itself and of supplementary science discovery materials.

We propose a 3 year collaborative interdisciplinary project (Figure 1) between The Children's Museum of Utah, TCMU (Appendix A) and the University of Utah's Center for Integrated Science Education, CISE (Appendix B). Protein Solutions, Inc.(PSI), a local company specializing in materials for science education, will provide the bioluminescent organisms and technology as needed (See Appendix D-Letters).

We will develop and produce interactive bioluminescent activities, combine them to produce comprehensive exhibits, and prepare and provide supplementary discovery materials and kits.

The overall goal of this exhibit within the Children's Museum of Utah is to provide the visitor with an introduction to science discovery, observation, hypothesis development, and experimentation. He/She will discover that all disciplines of science are interrelated and there is still much to be discovered and explored. The visitor will leave with a feeling of success and accomplishment and the motivation to learn more through discovery and questions. The take home items will provide a medium for continued discussion of his/her new-found discoveries.

This proposal is a resubmission. Based on the reviewers' critique (April 1-3, 1992) and on our growing experience with the topic, we have completely redesigned the exhibits and revised the proposal. The following quotes are from the Summary of Reviews of MDR 92-53160:

> "The potential of the topic is this project's greatest strength. Most reviewers commented enthusiastically 'I love the concept....' 'Very exciting exhibit concept.' 'A fascinating idea....' The topic is excellent and reviewers thought the exhibits sounded interesting."

> "Some reviewers encouraged the proposers to consider resubmitting another proposal because they liked the idea so much."

Each of the concerns raised by the previous reviewers have been addressed in this revised proposal, with much sharper focus on the activity station goals as they relate to specific educational and motivational objectives.

2.Design and Rationale

There is a growing awareness and interest in discovery and experiment-based science education activities (4, 5). The problems of our current science curricula are outlined in *Project 2061: Science for All Americans* (5). This report concludes that the problems in much of current science education include the "learning of answers more than exploration of questions, memory at the expense of critical thought, ... reading in lieu of doing"(5). PSI is addressing this critical need by developing materials, "toys", discovery aids, and new curricula supplements using the excitement of bioluminescence.

Utah's school spending per student is fiftieth in the United States. Therefore, outside-of-class activities are important for the development of Utah's children -- especially in the sciences. To provide each Utah school with the necessary items to involve students in well-designed science projects is very difficult. The Children's Museum of Utah (TCMU) offers a central location, well-known for its educational emphasis, where interactive science exhibits can reach large numbers of children.

CISE has already presented a series of inservice courses for local elementary teachers titled, "Light from Life: Science in the Dark," with an exceptionally strong, positive, and enthusiastic response. Nine courses on Integrated Science Concepts and Themes are being conducted from January 15 through April 15, 1993 (Appendix D). These use bioluminescence as the means to experience the scientific process and the wholeness of science. The teachers and their students are interested in obtaining more information and experience with bioluminescence. The teachers recognize bioluminescence as an exceptionally strong tool for motivating students in science, and for the teaching of science as an integrated field of inquiry (Figure 3). They are requesting, indeed they are demanding, materials, exhibits, and additional experiences.

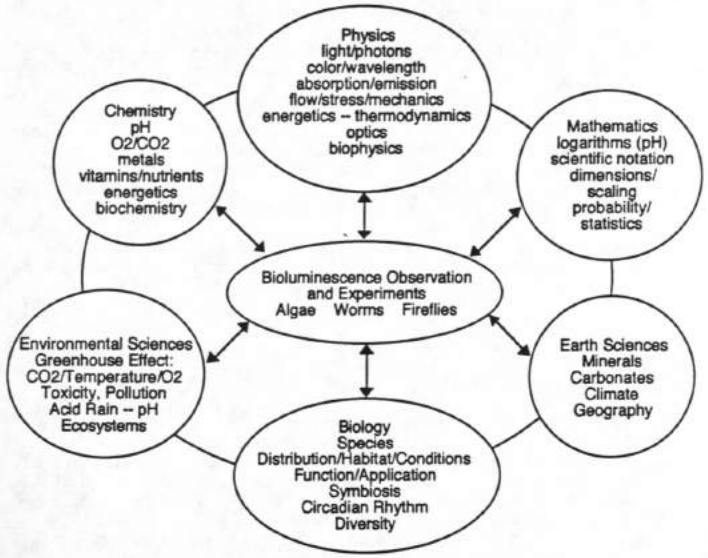

Figure 3: Bioluminescent organisms and their observation are shown as the center of an integrated science "wheel". Each of the classical specialties or disciplines are indicated with selected subject examples. These subjects and topics can all be directly observed and experimentally studied via bioluminescence.

TCMU's audience includes children from both rural and urban areas. About 25% of Museum visitors reside in rural areas. TCMU's off-site audiences include distant school districts, some coming hundreds of miles to visit. In addition to daily school groups and non-group visitors, TCMU housed an at-risk preschool for the entire 1990-1991 school year.

The bioluminescence project is part of a multi-year plan to develop TCMU's science facilities (Appendix A). The Museum has aggressive exhibit development activities in collaboration with the Center for Integrated Science Education. Through the strategic collaboration between TCMU, CISE, and PSI, we now have available technologies which make it possible to demonstrate and experiment with bioluminescence in a highly interactive inquiry-based mode.

The basic plan for the exhibit was given in Figure 2. After some preliminary orientation the visitors are directed into an entrance area which will be shaped more or less like a funnel. The outer regions will include some static display with various images and pictures of bioluminescent organisms in bright light. The right wall will be a static exhibit "Plants Come in All Sizes." This exhibit will be developed in cooperation with the Red Butte Gardens and Arboretum at the University of Utah. On the left wall a comparable exhibit "Animals Come in All Sizes" will be developed in collaboration with the Hogle Zoo in Salt Lake City (See Letters in Appendix). This is Station One (see Figure 2, Table 1). As visitors enter into the narrower part of the funnel, the size of the plants and animals displayed get progressively smaller. The light level also decreases as they enter so that it becomes progressively dimmer and finally nearly dark before they enter a black curtain which says "Welcome to Night Life." In the 10 feet or so prior to entering the curtain there are recessed displays of small and then micro organisms projected and magnified so as to be easily visible. Visitors will be able to see these displays without losing the dark adaptation which is a major objective of this cone-shaped entrance design.

At this point the guest will be introduced to protozoa life in a concise display located in the center of the aisle. They will be asked, "which side should you put them on?" It will be possible to place magnetic protozoa on either the animal wall or the plant wall. The goal at this point will be to focus the visitor on questioning, with the subsequent activity stations within the exhibit soliciting more questions, assisting the guest in formulating answers, and motivating them to fully engage themselves in this hands-on, experiential process. Guests then enter through the black curtain into a very dark world and approach Night Fountain (Station Two).

In Station Two, water comes from the ceiling into a small terraced, cascading pool. The water is a highly dense culture of bioluminescent dinoflagellates, microphytoplankton which produce a brilliant blue bioluminescence when stimulated mechanically, such as by water turbulence. The audio background will augment their own personal experience and discovery. With each drop, a brilliant blue bioluminescence is emitted from the point of contact; the light moves radially outward with the ripples. Bioluminescence is mechanically stimulated, generally by pressure and force changes in the water. This is a dramatic observation and immediately results in a wide range of questions. The objective of this station encourages formulation of questions and hypotheses. The visitor also becomes fully dark adapted to make the remaining stages of the exhibit even more impressive.

This dynamic station is mainly to initiate the bioluminescence experience, it is not designed to be touched or felt, although the visitor may control the flow of the fountain to some extent.

Station Three is next, tentatively called "Light Site." There will be a set of Light Sites, each with a set of chairs or stools. A group of visitors can surround each circular desk. The top of the desk will contain heavy transparent polyethylene bags containing high density cultures of the same bioluminescent dinoflagellate. By simply touching the bags, the microorganisms light up with their characteristic brilliant blue light. Visitors will be able to make a variety of patterns. They can write their name by pressing and running their fingers over the panel, analogous to what one does with a Magic Slate®, or a touch sensitive computer screen. The bag contains a suspension of the same bioluminescent microorganisms. The visitors' names (or other patterns they trace) are illuminated in the beautiful blue light. The light emitted in response to their touch does not last; it is transient and only emitted *during* the mechanical stimulation, which adds to the aura and the mystery -- and produces more questions.

Questions which were generated at the Night Fountain really become pronounced now, because the light is largely under their control: Why is the light blue? What makes it turn on? Why does it turn off? Where does the light come from? Where are the bulbs, the batteries, the electricity?

The fact that the visitors have seen a static exhibit of bioluminescence in the entrance foyer, and have been exposed through the world of microscopic plants and animals just prior to entering the exhibit, will suggest to them that this light may be produced by living organisms. Other hints will be given by the displays, the audio background, and the docents/explainers in the exhibit.

As they move to Station Four, it is expected that they will start formulating hypotheses regarding these bioluminescent phenomena. At station 4 they see the same water suspension now literally flowing through a 35 mm slide projector. The slide holder will be modified to permit the flowing suspension to pass through, producing a flowing current of dinoflagellates. The image will be projected on a wall using a high magnification lens which provides an inexpensive projection microscope of about 100 times. At this magnification, the pyrocystis lunula dinoflagellate, a half moon-shaped organism, about 200 microns in size, is about 2 cm in size. They will immediately see that the images produced are from the same solution they observed in Stations Two and Three, and may recognize that some of the same images were shown in the microworld exhibit in the entrance area. They will now be asked to become involved again by "catching" a dinoflagellate, that is extending their hand into the projected light, allowing one of the organisms to project on their hand. The projection will be quite large in order to get the 100 x magnification, and will appear on a white wall. As many as 10-15 visitors near the wall will be able to make their own shadow grams and otherwise interact with the projected light. One of the unique aspects of this organism is that it has a 7 day doubling time, which means that one will see cells in virtually all stages of cell division. There will be moon-shaped cells, round cells, cells in the process of dividing, cells which have just freshly divided; all stages of the life cycle are visible.

In Activity Station Five, a variant of the projection activity in Four, they will be asked to draw and trace their own dino. The idea is the same, only now a modified photographic enlarger will be used, again with the solution flowing directly through the enlarger, permitting the organisms to be projected onto a base. Students will be allowed to spend a few minutes at each of these enlarger stations. Enlargers are relatively inexpensive pieces of equipment, and are readily available to the museum by donation

from hobbyists who have given up the hobby. The same is true of the slide projectors in station 4. The only task involved here will be modifying them with the appropriate lens to get the magnification desired. With the activity in Five, each visitor has his or her own piece of paper or papers which they have produced with their pet or favorite dinos.

After Station Five, they are encouraged to sit down at various work desks and put together a set of puzzles and color pages, i.e. coloring books, related to the dinoflagellate images which they have just "caught". They will be asked to name their pet dino, and using available posters and displays as guides, various parts of the cell will be identified and labeled in this short exercise.

Stations Six through Nine are designed for slightly older children whereas Stations One through Five are appropriate for all museum audiences. Stations Six through Nine provide more sophisticated information for children, yet each station will contain small interactive components which will be designed to engage children of all ages.

The topic of food for the dinos is addressed in Station Six. Here is where we will demonstrate that the dinos are indeed plants through a series of bioluminescence exhibits in which cultures which have received light for photosynthesis and those which have not are observed for their bioluminescence intensity. Those which have not received light will be dead, because these organisms are microplants. Those that do receive light will be viable. This Station will include a set of activities related to photosynthesis which will connect back to the "Plants Come in All Sizes" display in the entrance region (Station One).

The visitor then moves to the animal world, Station Seven, asking "Who eats dinos?" Now the full concept of the food web and the food chain will be experienced These same dino cultures are now fed to small organisms, various microscopic zooplankton, which will be imaged and projected so they can be seen eating the dinos. Again a connection will be drawn to the "Animals Come in All Sizes" display in the entrance area, demonstrating the basic concept of the food web.

Station Eight includes the topic of ecosystems. Marine aquaria are used -- containing dinoflagellates, other phyto plankton and zoo plankton, and a range of other, primarily bioluminescent, organisms. This station will have two parts. On the right side will be an aquarium in full illumination. The lights will be turned off by the docent or guide. They will see that when one turns off the light during a normal "day", there is essentially no bioluminescence activity. The light will then go back on and they see a typical marine aquarium ecosystem. Behind it, however, is essentially the same marine aquarium, but in the dark cycle of the organisms' circadian rhythms. Now the docent and the visitors observe the fish swimming, stimulating the dinoflagellate bioluminescence! These aquaria are very specially developed marine tanks which are maintained using ecosystem/turf scrubber technologies, and do not require the normal filtration and high maintenance required by conventional display marine aquaria (21, 22). Aquaria using this technology have been operational in the laboratories of Protein Solutions, Inc. for the past year. Thus the microplankton organisms are maintained at full concentration in the aquarium at all times. Now the visitors will be told that the aquarium is in its night phase. By stimulating it, they will see bioluminescence and develop the concept that bioluminescence occurs at night -- that many of these organisms are on a biological rhythm and 24 hour clock.

The final exhibit (Station Nine) will be a static exit region with dramatic projected transparencies of bioluminescent organisms, most of them in their natural light. In

addition to the dinoflagellates, the invertebrates, and the fish which they have already observed, they will see mushrooms, fireflies, worms, and a variety of other organisms representing the thousands of species which are known to be bioluminescent (6-8). There will also be small video segments obtained from bioluminescence researchers, and appropriate public television, British Broadcasting, and related programs (11).

They then exit through the same entrance foyer through which they entered. Commercial versions of some of the videos shown, a series of books related to bioluminescence, and a series of science educational products based on bioluminescence will be available (9, 10). Guests will depart the exhibit with a bibliographic list of relevant science books and community resources for children and families, and a schedule of upcoming science events for children.

In addition to these materials, pre and post curriculum will be available at no cost for classroom teachers whose students visit the exhibit. TCMU and CISE will also offer biannual inservice training for teachers, coordinating state curriculum with TCMU's bioluminescence exhibit and educational programs, and CISE's state wide training activities.

Table 1 briefly presents each of the Stations, the educational and learning goals for each station, the observations and actions which will be made, and distills the principles and concepts which the visitor is expected to experience.

What will the typical visitor "take away"?:

1) the memory of having had successful, fun, and engaging experience in scientific exploration;
2) an increased interest and appreciation for diversity in biology (6, 12);
3) an increased awareness that science is not didactic and fully known -- an appreciation for questions and hypotheses;
4) an appreciation that life responds to physical and mechanical stimuli; and,
5) an appreciation of the inter-relationships among the disciplines and the wholeness and unity of science (5);
6) a bibliography of relevant science books and community resources for children;
7) a schedule of upcoming regional science activities for children and families;
8) the child's own drawings of protozoa and dinoflagellates.

Table 1: The Various Stations, Activities, and Science Principles/Processes in the NIGHT WALK Project:

Station/ Activity	Educational Goals	Observation/ Action	Principles/ Concepts	Implementation Date (Months)
1: Entry	Motivate questions on plants, animals	Animals/Plants/ Protozoa/ Macro -- Micro	Scale/ Dimensions Adaptation (dark)	6-18 (continuous Improvement)
2. Night Fountain	Introduce phenomenon, questions, begin to solve "puzzle"	Where does the light come from? Why is it blue? Do splashes make light?	Scientific Process/ Hypotheses -- light/color/ turbulence	6
3. Light Site	Further development of hypothesis	Touch, draw, shake, Why does it light when I touch it? Visitor controls light emission	Control/ Stimulation of a process -- hands on experiment	6
4. Catch a Dino!	Define protozoa and dinoflagellate, Q & A process as scientific process	Projection, Magnification, Focus, Microworlds	Optics, Magnification, Scale	12
5. Draw Your Dino! (Where is the baby dino?	Structure, reproduction	Drawing and Tracing, life cycle fission, magnification, focus	Recording observation, microscope	18
6. Food for Dinos (What do dinos eat?)	Light as food photosynthesis, food web, Q & A's	Light, color, absorbance, photosynthesis, habitat, maps	optics, filters, plants -- photosynthesis	24
7. Dinos for food (Who eats dinos?)	Plants as food, animals eat plants, food web, Q & A's	zoo plankton, invertebrates, fish	food web/food chain, animals/ plants	24
8. Marine Aquaria	Biological rhythms, patterns in the natural world, Q & A's	"Sim-Ocean", balance, Bioluminescent organisms in marine aquaria -- feed -- watch	Biosphere ecology	30
9.Bioluminescence	Intro of variety of bioluminescent organisms, hands-on fun as the basis for scientific inquiry	Other bioluminescent organisms	Diversity science -- what we do not know why	12-30 (continuous development)

NIGHT WALK

Science in the DARK!

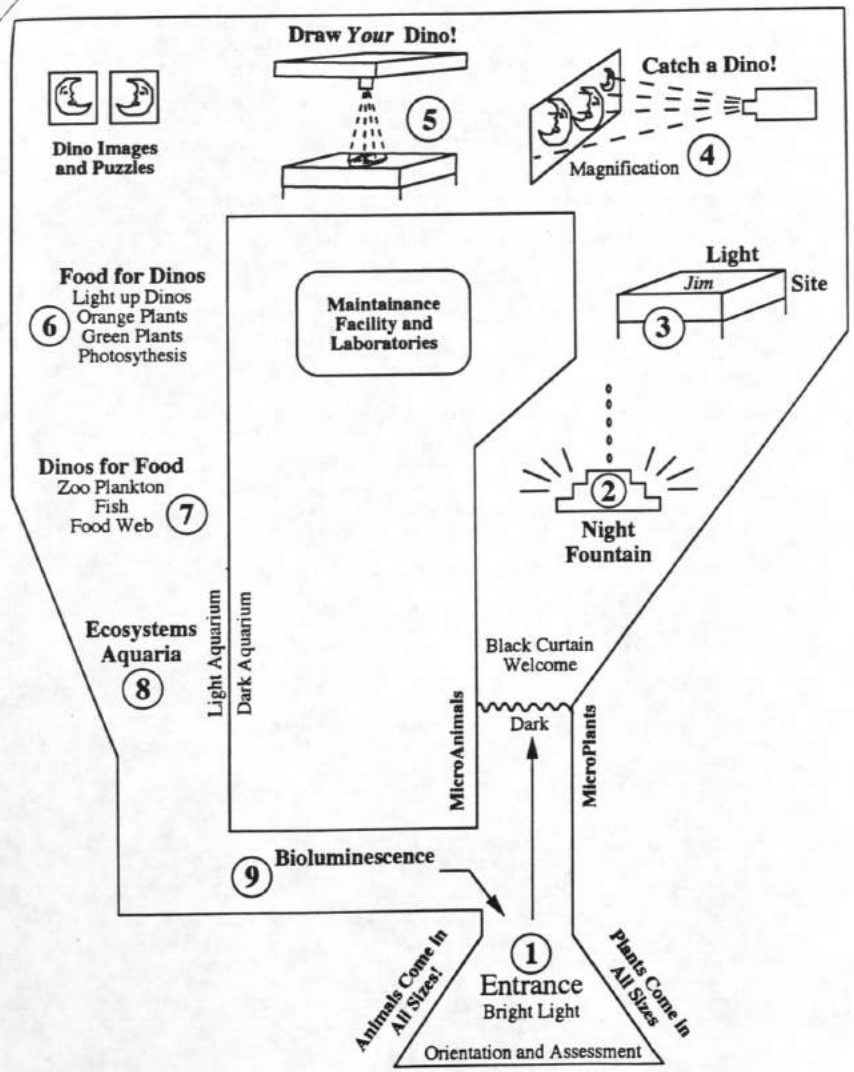

Figure 2: NIGHT WALK Exhibits and Activities

3. Timing:

The project will be accomplished over a 3 year period. In the first year we will use existing technology developed by the Center for Integrated Science Education (CISE) and Protein Solutions, Inc. and develop it into an interactive exhibit format. Stations 1-5 in seen Figure 2 will be implemented within the first year (Table). This will provide experience in transferring the relevant technology and expertise from CISE and PSI to the Museum; we will begin to train museum personnel to grow and maintain the organisms. It will also give us considerable experience with exhibit design, implementation, maintenance, and operation.

Prototypes of Stations 1-6 and 9 are now in use by the Center for Integrated Science Education for its inservice activities for Utah elementary teachers. Stations 7 and 8 are closely related to projects now ongoing by CISE and by Protein Solutions, Inc.

4. Educational Impact:

The educational mission of the Children's Museum of Utah is to provide opportunities for children to engage in high interest, intriguing, exploratory learning situations (4); situations which allow each child to feel successful in his/her exploration; and continue further investigation and learning.

The foundation for all scientific inquiry is learning through observation, direct experience, and discovery. The elements of observation, hypothesis, experiment, and conclusion are the basis for the scientific process.

Bioluminescence is an intriguing and highly motivating phenomenon. It is visually exciting, and accessible to children of all ages. Bioluminescence is an exceptionally effective medium for stimulating a child's interest in science.

By visiting this exhibit, the child will experience that:

- science is a process of observing and experimenting;
- there is much yet to be discovered in science;
- bioluminescence is a varied and diverse phenomenon.

The child will feel:

- successful in his/her attempts to explore bioluminescence; and will be
- motivated to learn more about bioluminescence and other areas of science.

The child will depart the exhibit with:

- his/her own drawings and sketches
- a bibliography of relevant science books for children;
- a list of upcoming science workshops for children within the Salt Lake City area.

One of the real advantages of bioluminescence is that it is an unknown phenomenon. It is not usually found in textbooks (9, 10). No one has flunked it; no one has developed science anxieties towards it. Students, teachers, and parents are exceptionally receptive to it; they are curious and highly motivated as we have observed through our experience with inservice training and classroom presentations. It is an ideal vehicle by which to teach science in an integrated fashion (Figure 2).

A record will be maintained for each visitor. They will be invited to participate in evaluations of the exhibits and in bioluminescence contests, special exhibits and lectures. Our intent is to keep them involved -- keep them interested and learning!

5. Monitoring and Evaluation

Visitors come to museums and to exhibits with a certain base of knowledge and with preconceived ideas and even conclusions about science. In many cases these ideas and conclusions are inappropriate or incorrect. (13-16) These have been called naive theories in the education literature. (4, 16) The process of education involves discovery of new concepts and information which then challenges the naive theories. The student or visitor is then involved with a struggle wherein he/she must match their naive theories and expectations with their new experiences and discoveries. This leads to a reconstruction or restructuring, which results in a more reasonable or correct view of nature and of science. (4, 13-16)

The collaboration between TCMU and CISE provides access to two experts on this subject in the Graduate School of Education, Department of Educational Studies, at the University of Utah: Dr. Trish Stoddart and Dr. Julie Gess-Newsome. Both have worked extensively in this area. J. Andrade has collaborated with each of them in a number of other projects related to the development of science education materials and undergraduate science course experiences for elementary teacher candidates. (11, 17, 18). Drs. Stoddart and Gess-Newsome will advise the project in terms of audience and student assessment related to bioluminescence observations. Their results will be invaluable in the design and development of the exhibits and the instructional and descriptive materials related to them. They will be involved in both pre-assessment and post- assessment of exhibit visitors and will work closely with TCMU and CISE staff in assuring the most effective, interesting, and educationally relevant discovery experiences for the Night Walk series of exhibits.

A pre-test and post-test will be administered to each tour group which visits the exhibit (17). The exhibit's stated objectives will be assessed, including specific information on the scientific process, bioluminescence, an attitude inventory, autobiographical information and teacher observation. The evaluation tools will consist of:

1. Pre-test: a coloring "puzzle" which directs the child to locate a key within the picture, color it, and answer several questions. Completing this puzzle will create the "key" which will "unlock" the door to "Night Walk."

2. Post-test:
   A. a drawing activity, thematically linked to the "key" which opened Night Walk, which assesses information acquisition and attitude.

   B. a student and teacher assessment will be sent to the classroom. Completion of short student essays and the teacher observation form will qualify the class to be official members of the TCMU Night Walk Club. The class will receive a Night Walk poster, which each child will sign, for display in their classroom.

The above assessment plan will be conducted throughout the first 24 months of the exhibit. At the end of this period the assessment plan will be evaluated, appropriately

redesigned, and reinstated. It is expected that review of the assessment will guide continuing exhibit development efforts for years 2 and 3 and beyond.

6. Organization and Management:

Research and development, organism production, and preliminary exhibit design will be conducted by the Center for Integrated Science Education at the University of Utah. Dr. Joe Andrade, Director of that Center and Investigator on this project, has four years of experience in bioluminescence, has conducted a variety of teacher inservices and demonstrations relating to bioluminescence, and already has the technology and experience in hand for Stations One through Five in Figure 3. Andrade and his staff will also be primarily responsible for the educational materials and kits which will become available. The Center sponsored a Utah Bioluminescence Contest in 1991, is sponsoring another such contest in 1993, and is mapping the location of bioluminescent organisms in the State of Utah. Andrade has been in communication with bioluminescence experts throughout the world.

Andrade has Department of Education Eisenhower Program support from the State of Utah, local foundation support, and local industry support for the use of bioluminescence for science education (Appendix D). All of those activities are directly relevant to this project. He is spending about 50% of his time on bioluminescence-related science education and research activities.

The design, fabrication, and installation of the exhibit will be done both by the staff of the Children's Museum of Utah and by external vendors. This process will be coordinated by TCMU's Exhibit and Education Director, S. Marsh. The exhibit design firm of Giltspur/Las Vegas will be the principle designers, with assistance from TCMU's staff. Fabrication of the activity stations will be done exclusively by Giltspur. Approximately fifty percent of the structural build out of the space will be done by TCMU's staff, with fifty percent being completed by Giltspur. The laboratory will be constructed primarily by TCMU and Protein Solutions.

Children's Museum staff and personnel will be trained in CISE laboratories on the maintenance and operation of the cultures and of the exhibits. The group will then establish an appropriate laboratory at the Children's Museum for this purpose. CISE and TCMU will develop and distribute curriculum which will directly complement the state curriculum standards, and Protein Solutions and TCMU will provide supplementary materials available for purchase on site.

7. Advisors

Dr. Watson Laetsch, former director of the Lawrence Hall of Science in Berkeley and former president of the Association of Science and Technology Centers, is a key member of the advisory team. Dr. Laetsch is now a consultant to groups developing Science and Discovery Centers throughout the world. He is now a consultant to the Task Force for a Utah Science Center (J. Andrade serves on the task force).

Dr. Lawrence Lowery, professor of science education in the Graduate School of Education at University of California, Berkeley, is a senior researcher at the Lawrence Hall of Science. He is an expert in the development of children's scientific concepts and the design of science curricula and instructional methods. He is PI of the Full Option Science System (FOSS), a novel science instruction/discovery curriculum now being implemented widely throughout the United States. He has worked on a variety of projects related to interactive science education and has received many awards.

Carol Ebright, a first grade teacher in Roosevelt, Utah, was a teacher participant in CISE's first Utah Bioluminescence Contest. Ebright's student, Michael Seeley of Roosevelt, Utah, was the winner in that contest for his discovery of fireflies in Eastern Utah, an area of the country normally reported to not contain fireflies.

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 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 of problem solving skills in minority elementary school children. Ms. Spencer is of Afro-American heritage.

CISE's National Advisory Board also includes scientists with expertise in each of the bioluminescence areas to be included in the Night Walk exhibits.

Dr. Woody Hastings is professor of biology at Harvard University. Dr. Hastings is internationally recognized for his work on bioluminescent dinoflagellates, the phytoplankton protozoa which are the basis of exhibits 1-5. Dr. Hastings has been advising us for the past two years on the various aspects of dinoflagellate culture and physiology. It was much of this work which led to the current Night Life product now being marketed by Protein Solutions, Inc. Dr. Hasting's work on the use of dinoflagellates for the study of biological rhythms was recently featured on the educational television series, The Infinite Voyage, in the segment "The Living Clock." He is internationally recognized for his work on bioluminescence of dinoflagellates and bacteria (8).

Dr. James Morin is professor of biology at UCLA. A former student of Dr. Hastings, Dr. Morin is an expert on bioluminescent organisms of many kinds, including bioluminescent fishes and the symbiotic bacteria which are responsible for the bioluminescence in many fish species. Dr. Morin is particularly expert on cypridina species, small crustaceans found in the Sea of Japan. He has recently discovered a large number of such species in the Caribbean. His expertise will be particularly valuable in exhibits 7-9.

William Kelley is one of the founders of Aquarium Systems, the makers of Instant Ocean and Reef Crystal, two of the most widely used artificial sea water preparations for exhibition aquaria as well as for home marine aquaria. Mr. Kelley is now retired in the Salt Lake City area. He is working closely with Protein Solutions, Inc. in the development of full scale dinoflagellate marine aquarium exhibits. He is also working on the culture of fish in various artificial marine environments. His experience on the chemistry of artificial seawaters will be invaluable in developing exhibit 8, which will involve a wide variety of bioluminescent species in an exhibition aquarium.

This outstanding technical group and our excellent group of educators guarantee that we have substantial advice and input into the various aspects of the project. Their advice and criticism will ensure the scientific accuracy and completeness of the various exhibits as well as the effectiveness of the exhibits in terms of science education of the visitors and of the general public. In our collaboration with the Task Force for a Utah Science Center and with the Center for Integrated Science Education, we anticipate a significant number of other visitors who will provide input and critique during the various stages of the project.

8. Dissemination

Talks and workshops on the development and implementation of the various Night Walk exhibits and activities will be given regularly at the annual meetings of the Association of Science and Technology Centers, The National Science Teacher's Association and The American Association for the Advancement of Science.

Papers and publications will be submitted to the journals published by the National Science Teachers Association, journals and magazines dealing with museums and interactive science exhibits, as well as professional association newsletters, such as the newsletter of the National Science Supervisors Association, and The National Middle School Association.

The Center for Integrated Science Education is committed to participating in all relevant and appropriate science education related symposia, conferences, and workshops.

As the project progresses, particularly in years 2 and following, CISE and TCMU will also produce a demonstration video of the various components of the Night Walk exhibit (11). These videos will be made available by loan or at low cost to others interested in using bioluminescence for informal science education.

The plan is for the two institutions, in partnership with local industry, to produce and disseminate materials and exhibits to other museums and institutions nationally and even internationally. We expect that these activities will eventually provide a modest income to help sustain and develop this exhibit.

Commercial dissemination of bioluminescent products, supplies, and instructional materials will be handled by Proteins Solutions, Inc. (PSI), the corporate partner in the project (see Figure 1). Protein Solutions is already marketing a bioluminescent product, Night Life-Science in the Dark, an educational kit, in local toy stores, science product stores, and museum stores (19). PSI is in the process of preparation of science fair and teacher's manuals for its Night Life products. These educational materials will cover portions of exhibits 2-5 in the Night Walk exhibit. (See Figure 2) PSI is working with two large marine aquariums in the development of public exhibits involving dinoflagellate bioluminescence.

The Children's Museum of Utah and Protein Solutions, Inc. are negotiating an agreement by which to market and disseminate the Night Walk exhibits to other museums and science centers. It is expected that PSI will be responsible for the commercial dissemination with the appropriate payment of royalties to the University of Utah and the Children's Museum of Utah.

9. Work Plan and Summary (refer to 2. Design and Rationale) Fig. 2 and Table 1

Activity Station Two, Night Fountain, is already functional on a small scale. Drops of highly concentrated solutions of dinoflagellates are allowed to drop into a pool of dinoflagellates. The mechanical stimulation caused by the drop hitting the surface, as well as by the mechanics of the surface tension at the air/liquid interface, causes the organisms to bioluminesce. The result is a beautiful pattern of lighted drops in midair impacting the body of water and resulting in radial waves of bioluminescence in the pool. The pool water is then recycled back into a larger volume culture vessel. We anticipate no major problems in the scale up of this exhibit. Its major purpose is an attention getter and as a means for the visitor to spend a short amount of time in a dark environment-to

allow his/her eyes to become dark adapted, which will make the rest of the exhibit far more dramatic and impressive.

Station Three is again a culture of bioluminescent dinoflagellates, but this time enclosed between two transparent polyethylene sheets. PSI has developed this technology previously and intends to market a new product, to be launched by March 1, 1993, based on this technology (20). The gas exchange through the polyethylene bag is sufficient to maintain satisfactory conditions for several months. Fresh dinoflagellate suspension will be pumped slowly through the Light Site, from (and back to) large dinoflagellate cultures maintained in a culture room adjacent to the exhibit. As the dinoflagellates bioluminesce, they use up the chemicals needed for the bioluminescence reaction. By continuously pumping fresh culture through the bags, they will always be responsive to the visitors' actions.

The visitor will mechanically deform the polyethylene surface by writing his/her name or drawing various patterns with his/her finger. The mechanical stimulation of the dinoflagellates will cause their bioluminescence. Thus the visitor will be writing or painting on this "living panel".

Station Four will begin to answer the question of what exactly is responsible for the light emission. A very thin stream of the dinoflagellate culture will flow continuously through a high magnification slide projector. This is done routinely in teacher inservice courses and classroom demonstrations. A 35mm projection slide, manufactured by Carolina Biological, Inc., is designed to hold a small volume of solution. The solution in this case is a concentrated culture of dinoflagellates. By simply projecting this slide on a wall, one has effectively a 50 to 100x magnification and can readily see the dinoflagellates. They can be seen in a variety of different stages of cell division. Although most of our experience today has been with pyrocystis lunula, a non motile species, development is ongoing at PSI with various flagellated species which are actively motile. It will be particularly exciting to see the various species co-cultured together, moving and swimming around one another.

A variety of scientific principles and skills will be experienced and derived here. For example, the concept of optical magnification and microscopic examination and the analogy between the slide projector and an optical microscope. Visitors can easily measure the motility (velocity) of the various organisms by simply measuring the distance on the wall and recording the time elapsed. Examples of these principles will be posed in visual and audio displays adjacent to this station.

This very versatile exhibit minimizes the need for optical microscopes. Microscopes have the problem that only one visitor can experience the scope at the same time. Although this problem is alleviated somewhat with projection scopes, it is inexpensively obviated by the use of simple slide projectors.

Activity Station Eight is a marine aquarium which will contain a variety of bioluminescent organisms, including marine worms, jellyfish, shrimp, sea pens, and several bioluminescent fish. Working with Dr. Bill Kelley, CISE and Protein Solutions, Inc., are now involved in a study of the compatibility of various bioluminescent organisms in exhibition aquaria. As that work progresses, we will have the information required for including an aquarium with several bioluminescent species as part of the overall Night Walk Exhibit. Two or three aquaria may be included in the exhibit, each with different chemical conditions, temperatures, and light conditions.

Activity Station Nine will be a conventional static museum exhibition, showing the wide range of bioluminescent organisms in nature. This will be tied to the biological classification map based on "Five Kingdoms" and on the literature on characterization and classification of bioluminescent organisms (4, 29, 30). We anticipate a large panel mural illustrating various organisms and their bioluminescent properties. This will be a simulated exhibit. Fortunately there is a beautiful bioluminescent exhibit in the Yokosuka City Museum in Japan, which Dr. Haneda has developed into the most complete bioluminescence museum exhibition in the world. This will be used as a guide for this Station.

Finally the visitor will exit through a gift shop which contains a wide array of books, science kits, videos, and other materials related to the Night Walk Exhibit. The royalties and income derived from these products will help maintain and expand the exhibit after the years of NSF support.

A set of take home materials will be available for every visitor, to encourage them to share their discoveries and experiences with other members of their families, neighbors, school mates, etc.

There will also be a record of all visitors for periodic follow-ups, including announcements of new and expanded exhibits, other museum activities.
The idea is to keep the visitor involved with science discovery and to encourage them to share their experiences and discoveries with a larger group.

10. Financial Arrangements:

See Budgets, Budget Justification, Figure 1, and Appendix C-Letters of Support.

11. Summary:

Exhibit Design and Implementation will be a joint effort of CISE and TCMU. Drs. Stoddart and Gess-Newsome will consider preconceptions and "naive theories" in the intended audience. Marsh and Andrade will work closely with Stoddart, Gess-Newsome, and other co-workers in designing the exhibits and instructional materials. Exhibit implementation will be at TCMU.

Space is available for the exhibit-the remodeling which will be required will be covered by other funds. We are planning for a 1000 sq. ft. exhibit area, with an additional 300 sq. ft. lab and maintenance facility adjacent to the exhibit room.

Exhibit Operation and Assessment will be the responsibility of TCMU, although CISE staff will of course be involved, particularly for exhibit improvement and upgrading. Drs. Stoddart and Gess-Newsome will work with TCMU staff to assess audience involvement, interest, and understanding. The project Advisory Board will provide considerable advice and input. The projects and the exhibits will be thoroughly evaluated annually and assessed by the Board as well as by local advisors.

The Exhibit implementation schedule was given in Table 1.

Bioluminescence is a nearly ideal phenomenon with which to discover and integrate many areas and concepts in science (Figure 3). Our goals are discovery, curiosity, and understanding of concepts and principles. The exhibits are designed to provide a scientific experience-observing, questioning, hypothesis formulation, further

observation, etc. Our goal is not solely to entertain, which is a criticism of many scientific "fun and games" exhibits in some contemporary science centers. We intend to generate interest and develop motivation; we also expect the visitor/participant to develop some understanding and go away feeling that he/she learned something.
Bioluminescence light emission is the attention getter and the key observable (The frog in Dennis' cartoon):

Dennis The Menace by Hank Ketcham

"WATCH THIS, DEWEY... WHEN THAT FROG THINKS HE'S GOT OUR ATTENTION, HE'S GONNA TRY TO TEACH US TO COUNT OR SOMETHING."

Dennis and his friends will leave TCMU saying, "See, I told you we'd learn something!"

The key is to achieve a balance between "fun and games" and scientific observation, discovery, and understanding. We will attempt to challenge their minds while avoiding the "Mr. Osborne effect":

"Mr. Osborne, may I be excused?
My brain is full."

I. BIBLIOGRAPHY AND NOTES

1. National Geographic Magazine has had many articles and photos of bioluminescence:

   P.A.Zahl, Nature's Night Lights, July, 1971, p.45,
   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:

   K.H. Nealson and C. Arnesan, "Marine Bioluminescence: About to See the Light," Oceanus 28(3)(1985)13.
   P. Huyghe, "Wheels of Light, Sea of Fire," Oceans, Dec, 1987, p.21.
   M. Root, "Glow-in-the-dark Biotechnology," Biological Science 38 (11)(1988)745.
   A.K. Campbell, "Living Light," Trends in Biological Sci. 11 (1986)104.
   A.P. Neary and C.S.J. Walpole, "Bioluminescence-Chemical Light," Science Progress 70(1986)145.
   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. Howard Gardner, *The Unschooled Mind*, Basic Books, 1991.

5. J. Rutherford, Project 2061: *Science for All Americans*, American Association for the Advancement of Science, Washington, DC, (1988) p. 14.

6. L. Margulis and K. V. Schwartz, *Five Kingdoms*, Second Ed., Freeman and Co. 1988.

7. P.J. Herring, "Systematic Distribution of Bioluminescence in Living Organisms," *J. Biolum and Chemilumin. 1* (1987) 147-163

8. J.W. Hastings, "Biological Diversity, ...Bioluminescent Systems," J. Mol. Evol. 19 (1983) 309.

9. 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.
   P.J. Herring, A.K. Campbell, M. Whitefield, and L. Maddock, *Light and Life in the Sea*, Cambridge University Press, 1990.

10. 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.

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

12. E.O. Wilson, *The Diversity of Life*, 1992.

13. J. Renner, M. Abraham, E. Grzybowski, and E. Marek, "Understandings and Misunderstandings of Eighth Graders of Four Physics Concepts Found in Textbooks," *Journal of Research in Science Teaching*, 27 (1), (1990), pp. 35-54.

14. R. Biddulph, *Primary Science: The Views of Teachers and Pupils*, LISP Working Paper no. 102, 1982.

15. R. Driver, *The Pupil as Scientist?*, Milton Keynes: Open University Press, 1983.

16. M.G. Hewson and P.W. Hewson, "Effect of Instruction Using Students' Prior Knowledge and Conceptual Change Strategies on Science Learning," *Journal of Research in Science Teaching*, 20 (8), 1983, pp. 731-743.

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

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

19. 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.

20. John Tobler and J. Andrade, "Culture of Bioluminescent Dinoflagellates in Non-Traditional Media," Abstract, Utah Academy of Arts and Sciences, Salt Lake City, May 1991.

21. W.H. Adey and K. Loveland, Dynamic Aquaria, Academic Press, 1991.

22. W. Adey, "Ecosystem Encounters," Science Teacher, Sept. 1992, p. 22.\