THE EDUCATIONAL EFFECTIVENESS OF GEMS ACTIVITIES

In “The Educational Effectiveness of GEMS Activities,” the *GEMS Leader’s Handbook* summarizes a variety of research studies that demonstrate the general effectiveness of the inquiry-driven, activity-based approach to science education, including the classic studies of Bredderman, Kyle, Shymansky, and others, as well as the work of Karplus, Thier, Atkin, and others on the learning cycle. GEMS units and other curricula developed at LHS are grounded in this approach. The GEMS development team endeavors to stay abreast of new developments in educational research, new approaches to assessment, and to take such findings into account as guides are developed and revised. (Barber, J., Bergman, L, and Sneider, C: “The Educational Effectiveness of GEMS Activities” and Sneider, C. “GEMS and Research: Three Case Studies” in the *GEMS Leaders Handbook*, pages 19–32, 1988, 1994, 1997.)

From the inception of GEMS, the program has been involved in a number of collaborative projects funded by state and federal agencies, foundations, or corporate philanthropy. Many of these projects were based on curriculum sequences of GEMS units for primary and intermediate students and their teachers, sometimes in association with other activity-based curricula. Formal evaluations from a number of these projects indicate that the GEMS curriculum and instructional strategies have made a significant positive impact on student learning (as well as attitudes toward learning and on professional development). As relevant, pertinent aspects of these evaluations will be included under the appropriate headings. There are also several research studies that demonstrate the educational effectiveness of specific GEMS units, and their findings have been applied to the development of a significant number of other GEMS units.

These studies and evaluations indicate that the GEMS program:

- makes a significant and measurable difference in and impact on student learning;

- improves student and teacher understanding and practice of inquiry;

- has the demonstrated capability of reaching all students, including historically underrepresented groups, special education and gifted students, in a wide variety of settings and regions;

- fosters positive attitudes and motivation of students and teachers in science and mathematics; and

- has considerable additional evidence of effectiveness and success.

On the next page, as an organizer, is a listing of these evaluation reports and studies, which will then be more fully discussed under appropriate headings.

LHS GEMS

Results Contents Listing

Study on the Learning Station Approach
Trial Testing
Standards-Based Recommendations
GEMS Model Schools (or Districts).
GEMS Sites and Centers: Other Evidence of Success.

Evidence of gains in student understanding of science.

***Earth, Moon, and Stars* Research Studies:** An extensive body of research supports both the approach used and the level of educational effectiveness achieved by the GEMS unit *Earth, Moon, and Stars.* This research, including related studies and publications, contains strong evidence of gains in student understanding of two importance science concepts—gravity and the spherical shape of the Earth. Based on what research has determined to be major student misconceptions, the GEMS unit was developed and tested, then studies were conducted to determine the extent to which the designed unit made a measurable difference in student learning. Subsequently, lessons learned from this research have been applied to several other GEMS units, including *Moons of Jupiter* and the upcoming *Messages from Space: The Solar System and Beyond* (in press).

A full text of the first seminal article is attached. The study involved the application of Nussbaum's Earth Notions Classification Scheme to results of testing of 159 boys and girls from public schools in San Francisco, and the relation of these results to research conducted in Nepal, Israel, and Ithaca, New York. The classification scheme was itself subjected to rigorous analysis (see under "Results/Validation and Refinement of the Earth Notions Classification Scheme, page 211–217) with statistical and prediction analysis, resulting in a suggested refinement to include an additional notion between Notions III and IV in Nussbaum's classification. Results were analyzed based on age and grade, and in relation to previous research, and confirmed that children interpret information about the spherical Earth and gravity in terms of their own models of the world, and that these interpretations, while representing reasonable "alternative frameworks" from the child's point of view, require considerable additional learning experience to be transformed into accurate scientific conceptions.

The GEMS unit *Earth, Moon, and Stars* was intentionally designed and developed to help students overcome the misconceptions that were "unearthed" by the series of research studies, by engaging students in observations of the sky, and having them consider how alternative models can best explain their observations. The GEMS unit prominently includes a pre- and post-questionnaire, "What Are Your Ideas About the Earth?" which builds upon the experience of the previous studies, and in turn became a central element in the subsequent research studies of educational effectiveness of the GEMS unit. (Aside from these more formal studies, teachers are also instructed in the unit about how to use the questionnaire provided as a pre-test and post-test to assess the degree to which their students have comprehended modern scientific concepts about the

Earth's shape and gravity. The questionnaire, with actual student work, and instructions to the teacher on its use, are featured as a case study in the GEMS assessment handbook.)

Since the GEMS unit was developed, tested, and published, additional studies have evaluated the extent to which the activities in the unit succeed in overcoming student misconceptions. "Unraveling Students' Misconceptions about the Earth's Shape and Gravity," (full text attached) details a study involving 539 students from 18 classrooms in 10 different states. The experimental treatment was the GEMS unit, *Earth, Moon, and Stars*. The primary experiment was a treatment-group-only design, in which teachers (trained in the use of the questionnaire assessment instrument at a summer institute sponsored by NSF) administered the same test to all students before and after the treatment. The purpose was to determine the impact of the treatment on students' understanding of the Earth's shape and gravity concepts. Data were analyzed in three age groups (4th and 5th graders; sixth graders; and 7th and 8th graders). As expected from previous studies, on the pretest all classes displayed a wide variety of conceptions about these concepts. After the unit, however, the number of subjects who held misconceptions was far fewer. Chi-square analyses showed that a significant number of students at all grade levels shed their misconceptions concerning both the Earth's shape and gravity. A surprising finding was that younger subjects responded more positively to the experimental treatment than older students, so that, after instruction in the GEMS unit, fourth and fifth graders were as knowledgeable as seventh and eighth graders concerning the Earth's shape and gravity. While the GEMS unit was tested and found effective from Grades 4–8, the study suggests that this may indicate that presentation of the unit at the earlier grade levels may be particularly beneficial.

As Table 4 on page 279 of the Sneider Ohadi article depicts, percentages of students who demonstrated increased understanding of the Earth's shape before and after the GEMS unit went from 24% to 72% for Grades 4–5; from 27% to 45% for Grade 6; and from 38% to 62% for Grades 7–8. The percentage of students understanding gravity went from 7% to 67% for Grades 4–5; from 15% to 47% for Grade 6; and from 30% to 60% for Grades 7–8. In conclusion, the authors state: "…**The concepts selected for study by the students—the earth's spherical shape and gravity—were considered by many researchers to be of fundamental importance in allowing students to understand the modern scientific explanations of a wide variety of phenomena, such as the daily cycle of the sun, phases of the moon, and seasons. These findings were bolstered by a full-experimental, control-group study… supporting the conclusion that the constructivist teaching unit—*Earth, Moon, and Stars*, from the GEMS series—enabled large numbers of students to unravel their misconceptions and construct a more accurate model of the world."** (emphasis added). These studies, and additional studies and articles referenced below, have also had a significant impact on further curriculum development in GEMS, in particular on the *Moons of Jupiter* and *Messages from Space* units (see Sneider articles in collaboration with Varda Bar and others cited below on gravity in space, weight and free fall, and gravity and air). As the Sneider Ohadi study progressed, insights gained were taken into account as the GEMS assessment handbook was developed and as revisions of *Earth, Moon, and Stars* were published.

C. Sneider and S. Pulos. “Children’s Cosmographies: Understanding the Earth’s Shape and Gravity.” Science *Education* 67 (2) (1983): 205-221.

C. Sneider and S. Pulos, Evangeline Freenor, Joyce Porter, and Betty Templeton, “Understanding the Earth’s Shape and Gravity,” Learning ‘86, Vol. 14, No. 6, February, 1986, pages 43–47.

C. Sneider and M. Ohadi. “Unravelling Students’ Misconceptions About the Earth’s Shape and Gravity,” *Science Education* 82 (1998) pages 265–284.

C. Sneider, *Earth Moon and Stars* GEMS teacher’s guide, Lawrence Hall of Science, 1986, 1989, 1992, 1994, 1996, 1998.

C. Sneider with Varda Bar and Nathalie Martimbeau, “What Research Says: Is There Gravity in Space?” Science and Children, April 1997.

C. Sneider with Varda Bar, Barbara Zinn, and Rivka Goldmuntz, “Children’s Concepts About Weight and Free Fall,” Science Education, Volume 78, Number 2, pages 149–169, 1994.

C. Sneider, “Does Gravity Need Air?: A Force That Holds the Universe Together,” GEMS Network News, Fall/Winter, 1993, pages 26–29.

C. Sneider, “Shape of the Earth Assessment Task for Earth, Moon, and Stars,” GEMS Network News, Fall/Winter, 1993, pages 30–31.

Barber, J et al, *Insights and Outcomes: Assessments for Great Explorations in Math and Science*, “Case Study Using Pre-Post Testing, What Are Your Ideas About the Earth from Earth, Moon, and Stars,” pages 102–109.

Nussbaum, Joseph, “The Earth as a Cosmic Body,” in R. Driver, E. Guesne, A. Tiberghien (editors) *Children’s Ideas in Science,* Open University Press, Philadelphia, 1985

The Galaxy Classroom Project (Pilot Program 1991-1995) funded by Hughes Aircraft and the National Science Foundation: The Galaxy Classroom Project is a multimedia, year-long program for K–5 students in classrooms nationwide. A main goal of the K–2 component is to impact student learning of the science/mathematics concepts and processes of observing, comparing, communicating, properties of solids and liquids, structure/function of living organisms. The Pilot Program consisted of a core classroom curriculum from the GEMS and FOSS projects of LHS with two series of interactive television programs designed to incorporate the science and math concepts emphasized in the classroom program. Family home activities and classroom activities involving fax and the Internet are also included. The program is currently being conducted statewide in Georgia, in selected districts in California, elsewhere in the United States, and in Canada. **Since 1995, the Project revised their classroom curriculum to include only GEMS units.** The GEMS units for the K–2 program include *Terrarium Habitats, Liquid Explorations,* and other GEMS early childhood units. The 3rd through 5th grade program focuses on *Bubble-ology, Oobleck, Chemical Reactions, Investigating Artifacts*, and five others. As is typical of GEMS, several of these units also have a strong mathematics component. The executive summary of the final report of the Galaxy K–2 program show student gains in learning key concepts, improvements in teacher instructional practices, and an increase in curiosity of students. The evaluation gathered quantitative data on GALAXY'S impact on student learning through pre-post tests of observation skills and an assessment of the science content presented. The report also states: "Teacher reports and evaluation results confirm that most students understood the concepts of the two GALAXY themes (recognizing and comparing the properties of various liquids, solids, and mixtures and identifying and comparing the characteristics and features of insects." The report adds, "GALAXY first and second graders exhibited a striking and statistically significant growth in curiosity when compared to their non-GALAXY peers." (page1, Far West Laboratory, Final Report). The Far West Laboratory for Educational Research and Development (currently West Ed Laboratory) of San Francisco conducted the evaluation for the Galaxy Classroom Project. It was directed by Dr. Gloria Guth.

PEACHES I Project, funded by the National Science Foundation: In 1994, the Primary Education for Adults, Children, and Educators in Science-PEACHES Program completed a 4-year teacher enhancement project funded by NSF to improve the science and math teaching skills of preschool teachers and day care providers. The project conducted two 60-hour, 4-unit courses for early childhood educators based on 10 curriculum units developed by the program that contained developmentally appropriate science/math activities for 4-6 year olds. **Six of the ten units, *Tree Homes, Ant Homes Under the Ground, Ladybugs, Eggs Eggs Everywhere, Penguins and Their Young, and Mother Opossum and Her Babies* are part of the GEMS program—GEMS re-tests and publishes PEACHES trial versions, which then become GEMS units.** In the final evaluation, Project Evaluator Dr. Bo De Long conducted a study to measure changes occurring in preschoolers' knowledge about life science as a result of the project curriculum. Eighteen preschool-age children (from 3.4 years to 5.0 years) were administered individual interviews regarding their knowledge of and familiarity with the diets, habitats, and defense behaviors of various pond-, tree-, and ground-dwelling animals featured in the curriculum. These interviews consisted of open-ended questions designed to elicit knowledge about these animals as well as reveal the kinds of reasoning skills the children were employing when talking and thinking about life science. Students were administered the interview as a pre-test approximately one week prior to beginning the units *(Tree Homes, Homes on the Ground, Ant Homes Under the Ground,* and *Homes in a Pond)* and then again as a post-test approximately one week following completion of the units. The total time between pre- and post-tests was approximately three months. A control group from the same school was administered the same pre- and post-test separated by a similar three month interval. This group was included in order to ensure that any changes observed in the children's quality or quantity of factual knowledge as well as changes in the reasoning skills they applied were due to exposure to the curriculum rather than to expected developmental changes or learning effects due to testing. The original control group included twelve three- and four-year-olds, divided equally by sex—however, all but four females dropped out of the study due to moving, changing schools, or entering a new class where the units were being taught.

Children's understanding and retention of some of the content taught was measured by how well they could identify six animals presented in the units and by evaluating their responses to questions about the diet, habitats, and defense behaviors of those animals. Students were first given a dichotomous score (correct/incorrect) for their knowledge of the identity and behaviors of these six animals. The findings indicate that children exposed to the curriculum did, in fact, learn and retain content about the behaviors of the animals they are studying.

Table 6. Mean scores for content evaluation pre and post tests for treatment group and computed values of t for within-subjects matched group comparisons

Content area	Mean score pre test	Mean score post test	Computed value of t
Identification	4.3	5.0	2.140*
Habitat	3.6	4.6	2.769*
Diet	1.7	3.3	3.531**
Defenses	3.8	5.2	4.213***

Critical value of t at 17df = 2.110, $p < .05$*; 2.898, $p < .01$**; 3.965, $p < .001$***

Table 7. Mean scores for content evaluation pre and post tests for control group and computed values of t for within-subjects matched group comparisons

Content area	Mean score pre test	Mean score post test	Computed value of t
Identification	3.5	4.5	2.40
Habitat	3.5	3.5	1.0
Diet	1.5	2.0	.775
Defenses	4.75	5.75	2.45

Critical value of t at 3df = 3.182, $p < .05$*

Note: The accuracy of teachers' perceptions that children became more sophisticated in some of their cognitive skills because of the PEACHES/GEMS units was also evaluated. While sufficient evidence was not found for this, the great majority of teachers reported that their students' became better reasoners after they experienced the PEACHES/GEMS units, so this may merit further study. Insufficient evidence was also found for another teacher's report—that the units had a positive impact on sorting and classification skills. Again, a longer-term study might reveal qualitative gains in classification skills that were not demonstrated in this short-term evaluation.

Seabrook GEMS Site Studies. Myra Luciano of the Seabrook, Texas GEMS Network Site has conducted two studies. In the first, in 1997, on the GEMS unit *Build It! Festival* at her elementary school. she conducted a performance-based evaluation with a random sampling of 19 second and 24 fifth graders to determine whether or not students demonstrated improved learning in the areas of patterns, shapes, and spatial sense. The compiled data shows considerable improvement in recognition of shapes and spatial sense for both grade level groups. In 1999, Ms. Luciano conducted a study on the GEMS unit *Animal Defenses*, with 30 1st graders in the treatment group and 16 1st graders in the control group. The treatment group of 30 participated in the *Animal Defenses* unit the year before, when they were Kindergarteners. The 16 in the control group had never been exposed to the GEMS lessons. Both groups were asked to record all the animal defenses they were familiar with. The data by Ms. Luciano shows that the treatment group's median score was 4 words as compared to the median score of 1 word for the control group. The analysis by Eric Crane, School of Education, U.C. Berkeley indicates that the scores are significant if student factors such as age, grade, and teachers are taken into account. Further conversation with Ms. Luciano indicated that students in both groups were randomly distributed over three first grade classrooms at one school.

Evidence of gains in inquiry, reasoning, and problem-solving skills.

Experimenting with Model Rockets Research Studies: There is considerable evidence that the activities in the GEMS guide *Experimenting with Model Rockets* significantly improve students' conceptual understanding of controlled experimentation, as well as their abilities to design, conduct, and critique their own experiments and the experiments of others. The findings of this research have been applied to a number of other GEMS units that include a major focus on investigation and experimentation. The body of research evidence is summarized in the attached article "Learning to Control Variables with Model Rockets: A Neo-Piagetian Study of Learning in Field Settings" by Cary Sneider, Kevin Kurlich, Steven Pulos, and Alan Friedman. Dr. Sneider and others worked on the initial research in the late 1970s and early 1980s. With the help of a National Science Foundation grant (SED79-18976), a series of studies with students in diverse learning situations, including schools, scout organizations, and summer camps was conducted. A workshop for teachers and other youth leaders was held, to train them in presenting the activities. Both individual interviews and paper-and-pencil questionnaires were utilized before and after students took the class from their newly trained teachers. The research showed that **children from 9 to 15 years old could significantly improve in their abilities to design and critique controlled experiments as a result of the model rocketry course.** An article about these findings was published in 1984 in the journal *Science Education.*

The article (attached) includes an analysis of about 40 studies showing that positive results could be obtained in a wide variety of settings where students were given opportunities to perform controlled experiments, and summarizes this body of previous research (see Tables I, II, III, and IV, pages 466–470). The experimental treatment was the model rocket activities developed by Sneider. The study involved 275 children and adolescents, 9–15 years old. Four criterion tasks were developed and a scoring system developed (page 471 and Figure 1, page 472). Subjects were also administered cognitive tests. The details and results of Experiment 1 and Experiment 2 (designed see if the results of the first experiment would be replicated and to rule out alternative explanations for positive results, with both an experimental and a control group—who did not do the rocketry activities until after the study was over). Both experiments showed a that subjects did much better on the post-test than the pre-test. In Experiment 1, among many statistical analyses, multiple t-tests were performed to compare those who took part in the instructional program with those who had not, within appropriate age level groups. The results showed that all ages learned significantly, and that the model rocketry program was effective in teaching controlled experimentation for children and adolescents between the ages of 9 and 15, in schools and non-school groups, and for both boys and girls. The results for Experiment 2 were similarly positive. Interestingly, ANCOVA analysis of group task results showed a significant difference between pre-test and post-test, but no significant difference between the experimental and control groups. When results were analyzed separately for boys and girls, these anomalous results were seen to stem from the fact that girls in both the experimental and control groups showed improvement in both pre and post-tests. The paper speculates on possible reasons for this result, including possible communication between girls who had taken part in the activities and those who had not.

The overall positive results and other research-based information gained during the model rocket study formed the basis for the development of the GEMS unit *Experimenting with Model Rockets,* first published in 1989, and revised in 1991 and 1997. Lessons gained from the study, as well as the subsequent thorough local and national testing process to which all GEMS units are subjected, were crucial in creating and refining the GEMS unit. The same progression of activities validated in the study is retained in the GEMS unit. The GEMS assessment handbook, *Insights and Outcomes,* includes an updated and revised version of two of the pre-post pencil and paper tests used in the original study, "Experimenting with Cars," and "Experimenting with Plants," with instructions for how to use them both as an assessment for the GEMS rocketry unit (*Insights and Outcomes,* pages 224-227, 1995).

This research provides clear and compelling evidence that the GEMS unit *Experimenting with Model Rockets* helps students understand the concept of a controlled experiment, and improve their abilities to design, conduct, and criticize controlled experiments. Acquiring this key capability and understanding improves students' comprehension of what scientists do, and equips them with an important ability for living and working in the modern world. With the advent of the *National Science Education Standards and* their strong emphasis on both the ability to do and the understanding of scientific inquiry, this research and the instructional units that grew out of it can help make a significant contribution to the scientific literacy of students who experience these units. This research has helped guide the development of many other GEMS units. For example, the following GEMS units (in addition to *Experimenting with Model Rockets*) help students learn controlled experimentation and/or other related aspects of scientific inquiry and investigation:

- In *Hot Water and Warm Homes from Sunlight*, students are introduced to the concept of controlled experimentation through an activity sheet in which they reason about some plants that were given different amounts of fertilizer. They then perform pre-designed experiments, discuss why it is important to keep all of the possible variables constant, and can go on to design their own experiments.

- In *Bubble-ology*, students are introduced to a technique for measuring the size of bubbles so they can determine which of three soap solutions is best. They need conduct the tests so all variables are controlled except for the kind of soap solution.

- In *Paper Towel Testing*, students are challenged to design their own experiments to determine which brand of paper towel has greater wet strength, and which is more absorbent. They must identify the variables and design controlled experiments.

- Both *Acid Rain* and *Global Warming and the Greenhouse Effect* have key components involving student experimentation.

- In *River Cutters* students learn the distinction between systematic observations and controlled experiments, using their river cutting models to conduct a controlled experiment involving slope, and then designing their own systematic observation or experiment.

- In *Dry Ice Investigations* (in press) the intriguing behavior of dry ice provides a compelling way to systematically guide students through the entire process of investigation, from exploration through systematic observation and experimentation, with strong emphasis on areas that research has shown to be difficult for students, such as coming up with investigable questions and planning. *River Cutters*, *Dry Ice*, and a number of other GEMS units provide excellent platforms for the "full investigations" recommended in the *National Science Education Standards.*

C. Sneider, K. Kurlich, S. Pulos, A. Friedman. "Learning to Control Variables with Model Rockets: A Neo-Piagetian Study of Learning in Field Settings." *Science Education* 68 (4) (1984): 463-484.

Sneider, Cary I., *Experimenting with Model Rockets*, Great Explorations in Math and Science (GEMS) teacher's guide, Lawrence Hall of Science, 1989, 1991, 1997.

Barber, J et al, *Insights and Outcomes: Assessments for Great Explorations in Math and Science*, " Selected Learning Outcomes for Experimenting with Model Rockets, pages 224–227, 1995.

Barber, J., Bergman, L, Sneider, C: "The Educational Effectiveness of GEMS activities" and Sneider, C. "GEMS and Research: Three Case Studies,"*GEMS Leaders Handbook*, pages 19–32, 1988, 1994, 1997.

The GALAXY Classroom Science Project (for Grades 3-5): Evaluation of this project was conducted by Dr. Gloria Guth of Far West Laboratory (now WestEd). Galaxy is a package of integrated curricular and instructional approaches, supported by the nation's first interactive satellite communications network designed to facilitate the introduction of innovative curricula to improve student learning in elementary schools. The Galaxy Classroom Science for Grades 3-5 features the organization of instruction around themes presented through television broadcasts and classroom hands-on activities that are facilitated by fax technology and ongoing teacher support. **Classroom curriculum included 8 units from the GEMS program—*Earth, Moon, and Stars, Bubble-ology, Oobleck,. Investigating Artifacts, Crime Lab Chemistry, Fingerprinting, Chemical Reactions, and Of Cabbages and Chemistry.*** The evaluation found that GALAXY science for grades 3-5 is a highly successful initiative. For example:

- On measures of classification processes, GALAXY students had a statistically significant gain that was more than double the gain of non-GALAXY comparison students.

- Scores on curriculum-based performance assessments indicate that the majority of GALAXY students across all three grades were able to demonstrate that they understood the "big ideas" or core science concepts of the GALAXY curriculum.

- In general, when comparison non-GALAXY students were evaluated on some of the same measures, GALAXY students outperformed them in almost every case.

- In addition, GALAXY teachers displayed significantly more positive attitudes than they had initially regarding their own comfort with and preparation for teaching science and the adequacy of their science materials.

- Participating in GALAXY Classroom Science led to statistically significant positive change in attitudes among GALAXY students, when compared to their non-GALAXY peers, toward participating in science class and engaging in activities to which they did not know the right answer.

The Evaluation Approach: The evaluation gathered quantitative data on GALAXY impact by testing student learning through performance-based assessments, surveying student and teacher attitudes and teacher practices, and asking teachers to record their use of the GALAXY Classroom Science curriculum. Administration of four of the performance-based assessments and the attitude surveys followed a pre/post design. Four other assessments were more closely linked to the curriculum and activities, and they were administered during the course of GALAXY science.

Developing Scientific Thinking Processes and Results From Performance-Based Assessments: Researchers adapted four performance-based assessments from the California Learning Assessment System (CLAS) to test GALAXY and comparison students' progress in several crucial areas. Researchers measured classification and organization with two hands-on assessments using fossils in the pre-test and leaves in the post-test. Skills related to experimentation were measured by two other pre/post performance-based assessments using rocks and soils, administered in a crossover design. Additionally, students took a multiple-choice test of science process skills.

Results from the Classification Pre/Post Assessments: The evidence shows that participation in GALAXY had a statistically significant positive effect on students' classification abilities. These results are based on testing 600 GALAXY and 610 comparison students in the same grades at twelve GALAXY schools. Each of the two assessments had three tasks that were scored from 0 (no attempt) to 5 (accurate and informative). See Figure 1 in the Executive Summary to view the average (mean) scores for GALAXY and comparison students in each of the three grades, both before GALAXY science started (pre) and after it was completed (post).

Results from the Use of Scientific Thinking Assessments: Another assessment evaluated how students reason about and investigate the causes of unexplained phenomena. Overall, GALAXY students significantly more often chose a scientific explanation than a supernatural explanation than did comparison students. When asked to invent ways to prove their explanations, those who had participated in GALAXY were significantly more likely than comparison students to design an experimental approach. In sum, this evidence shows GALAXY achieved its goal of helping students understand the world through observation and experimentation and seek rational explanations for the way the world works.

Results from a General Test of Scientific Reasoning: An additional measure of GALAXY's effectiveness was a multiple-choice test designed to measure specific scientific thinking processes. It was given twice to GALAXY and comparison fourth and fifth graders, once when classes were one third of the way into the GALAXY sequence and once at GALAXY's conclusion. While fifth grade results were somewhat ambiguous, the fourth grade results showed advantages for GALAXY students in items testing skills such as experimenting and formulating correct hypotheses.

Curriculum-Embedded Assessments: In addition to comparing the performance of GALAXY students with similar non-GALAXY students, researchers assessed the GALAXY students on their level of mastery of the primary themes of the GALAXY curriculum. Curriculum-embedded assessments were used, together with videotaped performance assessments of small samples, to establish the degree to which the curriculum was achieving its goal of helping students learn about the core science concepts in each theme.

- **Curriculum Theme 1: Using Patterns as Evidence:** Approximately seventy-five percent of the 1,678 GALAXY students who completed the embedded performance task demonstrated a satisfactory capacity to use patterns as evidence.

- **Curriculum Theme 2: Doing Experiments:** GALAXY students performed five tasks associated with the experimental mixing of chemicals and recorded their findings for later scoring. Overall, between 65% and 70% of the 1,256 GALAXY students understood the concept of experimentation, could manipulate variables, and could predict probable outcome. Some students, however, had difficulty explicitly stating the cause and effect relationships among specific variables, a more demanding analytic task. The videotaped assessment provides strong evidence that GALAXY students approach unknown substances quite ready to experiment and with the understanding that they can systematically and collaboratively compare the properties of substances. (This was in contrast to comparison students, who had difficulty organizing themselves to work together and to begin to explore the problem systematically.) Taken together, the evidence suggests that the GALAXY experience made a positive contribution to student mastery of experimental methods.

- **Curriculum Theme 3: Building Models to Explain and Invent Ideas:** A paper-and-pencil performance test involving several common machines assessed students' ability to draw and explain models that showed how something worked or that could be modified to serve a new purpose. The 1,503 GALAXY students performed very well, with more than two-thirds scoring in the top two performance categories. The videotaped performance task, however, indicated that for both GALAXY and non-GALAXY students, the mastery of the process of going from design to testing was limited, with no apparent advantage to GALAXY students.

Evidence of improvements in course enrollment, graduation rates, and post-secondary school attendance.

GEMS and MESA Partnership (1991–1993). GEMS units have been used in many successful advancement programs, including MESA and afterschool programs of the National Council of La Raza. MESA has demonstrated considerable achievement in improving graduation rates and post-secondary school attendance, particularly in helping historically underrepresented groups advance in technical and scientific fields. GEMS has taken part in a number of formal partnership programs with MESA in California, training MESA facilitators and teachers in the presentation of GEMS units, including follow-up on teacher presentation of the units in their classes. The GEMS MESA Leadership Program, a series of workshops for educational leaders of the MESA program in southern California, was funded by McDonnell Douglas, and offered professional development workshops at California State University campuses in Los Angeles, Fullerton, and Irvine, and at Harvey Mudd College in 1991, 1992, 1993. Similar leadership workshops also took place in Sacramento, California. Workshops involved MESA teachers of science and mathematics in regional schools, as well as MESA advisors—college students working with younger students, who then used GEMS units as the instructional content in their Saturday academies. The grants provided for all schools involved to receive over 20 free GEMS guides, as well as some funds to obtain materials. In one case, for example, teachers reported back on GEMS units they had presented. Many presented *Bubble-ology*, *Earth, Moon, and Stars*, and *Oobleck*—in all 16 different GEMS units were presented in the three months following the initial workshop. GEMS units continue to be used by MESA and in many other comparable settings.

Evidence of narrowing the gap in achievement of accomplishment between diverse groups.

As noted, the GEMS unit *Experimenting with Model Rockets* was specifically designed to encourage the full participation of girls and young women in the activities and was successful in doing so. Experiment 1 of the study "Learning to Control Variables with Model Rockets" showed that both boys and girls were successful in designing controlled experiments. In the control experiment, Experiment 2, while both boys and girls did significantly better on the post-test, girls did even better than boys (boys, $t = 2.72$, $p < 0.025$; girls, $t = 3.24$, $p<0.025$). Dr. Sneider has explained that, in addition to model rockets having been a traditionally male domain, interviews and anecdotal evidence during early stages of the rocketry activities in the study suggested that the way the goals of the activity were framed had a significant impact on participation by girls/young women. As advisors on the study, partly funded by NSF, he enlisted the expertise of the

EQUALS program at LHS, then directed by Nancy Kreinberg, and involved leaders of the Girl Scouts of America to help address this issue and promote gender equity. Through a combination of what was learned through interviewing students as part of the study, and consultation with advisors, a major change in how the activities were initially described was proposed. It was found that girls were much more responsive to the activities when the teacher or youth leader emphasized that the object of the activities was to work together to design a good experiment in order to find out why some rockets fly higher than others (rather than a contest to see whose rocket flies the highest). The strong participation and success of girls in the study supported this approach. Several years later, during the GEMS testing process this lesson was emphasized and enthusiastic involvement of girls/young woman was again reported. Therefore, the GEMS guide instructs the teacher: "Emphasize that the goal is not for their rocket to fly the highest, but to design a good experiment, in order to find out why some rockets fly higher than others." (page 17, *Experimenting with Model Rockets*). The introduction to the unit explains, "Although boys have traditionally been more involved in building and launching model rockets, any initial reluctance on the part of girls is almost always overcome once the activity begins. It is important to stress to all students that the goal of these activities is to design good experiments to figure out why some rockets fly higher than others, rather than competing to see whose rocket flies the highest. Girls who wish to work together can form their own teams. Many of the organizations and advisors who took part in testing and modifying these activities were especially attuned to obstacles girls encounter in pursuing science and mathematics careers. This series of activities can enable girls to gain greater confidence, perhaps even helping 'launch' some on career paths that would not have been considered several decades ago." (*Experimenting with Model Rockets*, page 3, 1989, 1991, 1997).

The PRISM (Primary Institute in Science and Mathematics) Project (1990–1997)
The Woodside Consortium Evaluation was conducted by Dr. Steven Schneider and Susan Arbuckle. PRISM used many GEMS units as curricular exemplars, and the evaluation includes some data relating to equity. In the pre-institute questionnaire for the third summer institute, participants were asked to rank their current level of understanding in a number of teaching strategies and conceptual approaches, including "Equity strategies for teaching traditionally underrepresented groups including LEP, physically challenged, girls, and ethnically diverse classes." A paired T-test was conducted to test the level of significance of the outcomes of the pre- and post-institute levels of understanding. All of the strategies were found to be statistically significant ($p < .001$). For every concept, the level of understanding increased. In the pre-institute questionnaire, the mean levels of confidence ranged from 2.0 (weak) to 3.4 (strong) and in the post-institute questionnaire, the mean levels of confidence ranged from 3.5 (average) to 4.7 (very strong). While only

an indication via teacher surveys of increased attention to these issues, it is notable that this was one of the emphases of the PRISM program and that GEMS units were utilized to foster these equity strategies.

The Galaxy Classroom Project (Pilot Program 1991-1995) funded by Hughes Air and NSF. There are several anecdotal accounts from the Galaxy program that relate to this heading. A special education student at one of the urban schools "never misses an opportunity to let anyone within hearing distance know that he plans to become scientist so that he can 'do Galaxy stuff forever and ever!'" A third grade teacher in a "predominantly Hispanic school" told how one student of hers had never spoken, not one word. She read his file and found that his silence had been a concern for some time. She continues, "In my class he was very well behaved, he did his work, he simply never spoke. Since he has been working in the Galaxy classroom, he has changed. He talks now. He talks with kids in his cooperative group and he occasionally responds aloud to events in the show. We have been working with him carefully; he has come a very long way. This week he raised his hand to answer a question in class." *(GEMS Network News*, Spring/Summer 1994, pages 20, 21.)

Anecdotal Information: In addition to efforts to reflect and include he full range of diversity in GEMS publications and programs, as noted in other parts of the submission, we have considerable anecdotal information, along with written and oral reports from our national network of sites and centers to confirm that GEMS activities are often singled out by teachers for their accessibility to all students and their ability to both engage students who have not previously been motivated in science and mathematics and enable them to gain a sense of success. Classroom observation during the GEMS testing process pays special attention to the social composition and other special characteristics of the class. It was during local trial testing, for example, that GEMS staff members saw three boys who the teacher often had to send out to the playground with an aide because they were so disruptive become completely involved in one of the strategy activities from the GEMS guide *Frog Math.* In another class, testing the GEMS guide *Bubble Festival*, a boy whose family was homeless and who normally did not participate in class became, after a word of encouragement to the effect that (as the GEMS unit emphasizes) he could explore in his own way, focused for an entire class period on figuring out a creative way of measuring bubbles using non-standard units. He then started wondering about how to measure volume.

Other evidence of effectiveness or success.

Bridging Preschool and Kindergarten through Science and Mathematics–PEACHES Project II (1994-1998) funded by the National Science Foundation:

The PEACHES Project conducted a second NSF Teacher Enhancement Project in 1994–1999 to support the transition of preschoolers to Kindergarten through the use of PEACHES and GEMS materials and methodology. Over a 3 year period, 119 teachers and teachers/educators representing 28 teams of educators from across the country participated in intensive summer institutes and school year sessions to build cohesive PreK-K programs using content and skill-rich materials and instructional strategies integrating science, mathematics, and language arts. **The GEMS units that formed the core instructional materials for the project included: Animal *Defenses, Ant Homes Under the Ground, Egg Eggs Everywhere, Ladybugs, Penguins and Their Young, Tree Homes, Buzzing A Hive, Frog Math, Treasure Boxes, Bubble Festival*, and *Terrarium Habitats*.** The final evaluation of the project, conducted by Dr. Bo De Long, was designed to assess the impact of the project along six dimensions. Results from both qualitative and quantitative data sources confirm that the project had a positive, enduring impact in all six of the following areas:

- **The overall success and impact of the program on students, teachers, parents, and administrators.** Specifically, increases in teachers' confidence in teaching science, teachers' science content knowledge, teachers' use of inquiry-based teaching strategies, students' science content knowledge, and parental involvement were noted as evidence of the project's success.

- **The ongoing support of the staff and the effectiveness of various supporting aspects of the program.** Ongoing support was considered extremely important by the participants, and most reported that the support offered by PEACHES staff was essential to the success of the project.

- **The impact of the program on teacher practices and student outcomes in science and math.** Many participants stated that PEACHES Bridging program and GEMS curriculum had the single, greatest influence on their teaching practice, and that their entire approach to teaching had changed as a result of their experiences. The data showed that throughout the four years of the project, teachers gained practice and confidence in using inquiry-based teaching strategies in the classroom, helping to set a standard for inquiry-based practice early on in the school years for both teachers and students. This kind of early experience and training can help students develop inquiry-based skills that will impact their science learning throughout their school years. Ninety-five percent of the teachers reported that their students experienced "Large" to

"Very Large" increases in science content knowledge since they began using the GEMS units in their classrooms. In addition, teachers remarked on gains in students' ability to estimate, make inferences, and apply prior science/math knowledge to new learning situations in meaningful ways. Several teachers noted that students' facility with scientific language increased and that there were marked increases in the science facts and information their students knew. Because of the increase in use of inquiry-based teaching strategies, increases in student opportunities-to-learn can probably be assumed.

• **The degree to which the course materials and information are incorporated into on-going Kindergarten and early primary education programs.** The 119 original participants gave presentations, held workshops, or shared activities with about 7,600 teachers, 5,400 parents, 545 administrators, and 7,800 children. Many administrators said GEMS/PEACHES had become the core curriculum in their pre-K and Kindergarten science and math programs. At least four school districts have adopted the curriculum as their district pre-K and Kindergarten science curricula.

• **The effectiveness of the teams' ongoing activities with teachers, administrators, parents, and children in bridging the transition for preschool to Kindergarten.** In general, teams from all three cohorts more than met the bridging goals outlined in their original team plans. Even after two to four years, teams established at the Institutes continued to meet within and between grade levels to implement their plans.

• **The effectiveness of the program as a means of promoting collaboration between parents, teachers, and administrators.** Administrators and teachers reported increases in parent volunteerism in the classrooms, and received very positive feedback from parents about PEACHES Bridging as a program and about the amount of science content the curriculum is teaching their children.

The Primary Institute in Science and Mathematics (PRISM) Project, II, 1994–1997), NSF. The PRISM project, which used many GEMS units as curricular exemplars, was evaluated by the Woodside Research Consortium, co-directed by Dr. Steven Schneider and Susan Arbuckle, to assess the effects of the PRISM institute on participants' subsequent activities in the classroom and leadership efforts. Participants were contacted after they had been out of the institute for one, two, or three years. Interviews provided information about changes in the attitudes, teaching and leadership involvement of the participants over short and long term intervals. Use of the term "participants" below refers to both classroom teachers and teacher-educators who participated in the project.

Methodology: Successful phone interviews were conducted with 36 participants from the 1995 institute, 6 participants from 1994, and 7 participants from 1993. Three attempts were made to contact each individual. Teacher participants were asked to describe ways in which their exposure to PRISM has impacted their teaching and their students, the frequency of science and math instruction in their classroom, and the extent of their professional leadership activities. Teacher educator participants were asked to describe ways in which PRISM influenced the role they play with teachers. Teacher/Teacher Educator teams were asked about the functionality of the team post-PRISM. Interview data were collected, aggregated, then analyzed for trends, patterns, and the extent of professional activities related to the individual's participation in PRISM.

- **Changes in Classroom Teaching:** All teachers report their classroom practice has changed as a result of PRISM. Those who had taught little science, or who taught textbook-based math, felt the institute revolutionized their practice by showing them how to effectively implement readily available, investigative, hands-on science and math lessons and materials. All teachers utilize GEMS publications and express appreciation of the organization, thoroughness, and inviting nature of the materials.

- **Impact on Students:** All teachers have stories to relate of heightened enthusiasm among their primary grade students. A bilingual classroom teacher believes the changes in this teaching toward a more constructivist style "empowers" young children. One teacher comments that her students are learning more and different kinds of science than had she not participated in PRISM. Teachers state that their teaching is now "more real" for students, more student centered, and more developmentally-oriented.

- **Change in Amount of Science and Mathematics Instruction Time:** Almost all teachers devote more instructional time to science than they did before their PRISM experience. Those whose science teaching time remains unchanged were already firmly committed to daily science instruction—they report that although the number of minutes is the same, the pedagogy is more effective and the content richer.

- **Change in Specific Dimensions of Content and Pedagogy:** All teachers report utilizing inquiry-based teaching now more than before PRISM. Fifty percent of teachers interviewed estimate they use it 50% to 75% more often, and 50% up to 25% more often. Data reflects an increase in 1) engagement of students in activity-based science and math, 2) integrated science and math in the classroom, 3) cooperative learning techniques, and 4) constructivist teaching. The1997 Evaluation

Report from Woodside Research Consortium summarizes results from teachers and teacher-educators, with many quotes from participants.

As regards impact on student learning, the Year 3 Progress Report stated, “All PRISM participants report that their students are doing more mathematics and science. Moreover, the type of activities they do are inquiry-based, involving active learning modeled at PRISM. The students are more willing to take risks, approach problems and activities in a variety of ways, and have increased enjoyment of learning math and science. A bilingual classroom teacher reports changes in his teaching toward a more constructivist style. One teacher comments that her students are learning a far wider range of science topics than they would have without her attending PRISM. Teachers state that their teaching is more real for students—more connected to concrete events in students’ lives.”

Note: UC Berkeley graduate student Frank Worrell prepared the final evaluation report for the first half of the PRISM project. In regard to use of activity-based science and related variables, the Worrell report shows results of teacher surveys on pre- and post-questionnaires, indicating, on a 1-5 Likert scale (with 5 most favorable) significant increases from pre-questionnaire to one year later (page 8, Worrell report). Variables included: use of activity based science (increased from 4.2 to 4.9); stress on problem solving (from 4.1 to 4.3); teaches conceptual understanding (from 3.5 to 4.0); and teaches application of concepts (from 3.7 to 4.2).

Jacqueline Barber, Impact on Teacher Educators of 1-week participation in K-3 Math/Science Summer Institute. (web published on TEECH listserv)

GEMS by Satellite, An Interactive Model for Activity-Based Science In-service via Satellite Project, funded by the U.S. Department of Education in partnership with the GEMS Program and Educational Service District 101 in Spokane, Washington. The evaluation was conducted by Joan Shaugnessy of the Northwest Regional Educational Laboratory of Portland, Oregon. This project was conducted in 1990-1992 to provide training opportunities in the use of the GEMS materials for staff from rural and remote school sites. In its first year, the Project developed and disseminated 21 hours of inservice. Training and materials were made available at school sites to teams of administrators, teachers, and parents at thirty-six separate sites. During the second year of the program, videotapes from these broadcasts were produced to provide short orientation lessons that would train viewers who had been unable to watch the satellite broadcast. The units included in both the satellite training and in the development of videotapes were *Oobleck, Involving Dissolving, Fingerprinting, Buzzing A Hive, Bubble-ology, Liquid Explorations, Acid Rain,* and *Earth, Moon and Stars*.. At the end of the first year, the evaluator's conclusion was that satellite delivery for training was a positive experience for the participants. During the broadcasts, participants were engaged in GEMS activities and were enthusiastic about GEMS applicability to instruction in their own classrooms. Analyses of questionnaire data showed that the participants' ratings of the inservice format, interaction between participants and presenters, activities, and unit usefulness were very positive, averaging above 4 on the five point scale for five of the GEMS units. Satellite training reached the desired population successfully. Forty-six percent of the participating teams were from rural areas, forty-three percent were from remote regions, and sixty-one percent of the participating sites were Chapter I eligible. Upon completion of the satellite training, many teachers implemented lessons into their classrooms quickly. By the end of the 1991-92 school year, teachers reported they had used GEMS, on the average, for 10.85 hours of instruction. The large majority of teachers who used GEMS in their classrooms said the lessons were practical to implement, matched student learning needs and instructional style, and were appropriate for the grade level they teach.

River Cutters/AAAS Project 2061 analysis: In collaboration with Project 2061 of the AAAS, the GEMS unit *River Cutters* was carefully evaluated, with key issues pinpointed. It was then completely revised, in close coordination with Project 2061, to more effectively align its content and pedagogical support with main learning goals. The revised guide now addresses and in the words of Joellen Roseman of Project 2061 provides "much more instructional support" for several primary benchmarks (and their corresponding fundamental concepts in the *NSES*). These are: Benchmark 1B (6-8) #2 on controlled experimentation and issues of variables; Benchmark 4C (6–8) #2 and #5, on changes in the Earth's surface, including "The earth's surface is shaped in part by the motion of water and wind over very long times…" and on erosion prevention; and Benchmarks 11B (6–8) #1 and #3, on models, their usefulness and limitations. There are other important "precursor benchmarks," for earlier grades, which if not addressed can prevent students from attaining the primary benchmarks, especially in this case the 3–5 benchmark which states, "Waves, wind, water, and ice shape and reshape the earth's land surface by eroding rock and soil in some areas and depositing them in other areas sometimes in seasonal layers." This precursor benchmark is strongly addressed in the unit. In addition, based on the feedback of Project 2061, and the awareness that the vast scale of geological time is a difficult idea for students to grasp, the revised guide added and tested an entirely new activity, to provide greater instructional support for that aspect of Benchmark 4C which refers to "very long times." With this revision, the unit is judged to have been considerably improved by Project 2061 consultants and many teachers familiar with the unit. An article in progress by Project 2061 Curriculum Director Joellen Roseman and Former GEMS Curriculum Specialist Cary Sneider will confirm this improvement and document the process. The process was helpful and its essential elements are being applied to other units. Cary Sneider summarized the critique and revision process for the national science education community at a presentation entitled “Revising River Cutters: A GEMS Response,” presented at a colloquium entitled “Using National Science Education Standards to Evaluate, Select, and Adapt Instructional Materials,” conducted by the Center for Science, Mathematics, and Engineering Education of the National Research Council, Washington, D.C. November 15, 1996.

Science Core Assignments Program, New Standards Project, National Center on Education and the Economy (NCEE): In 1997–1998, the GEMS Project worked with Dr. Elizabeth Stage at NCEE to articulate a sequence of GEMS activities that build conceptual understanding toward selected National Science Education Standards (NSES) and AAAS Project 2061 Benchmarks objectives, as further defined by New Standards Project. Nine GEMS units were selected for grade levels 3 through 9. Each grade level series represents activities and assessments for 2–3 months of classroom instruction. The majority of these units are focused on science concepts, integrating portions of *Discovering Density*, *Convection: A Current Event*, and other activities related to the idea from the standards that: “Objects can be described by the properties of the matter from which they are made; those properties can be used to sort objects.” The NCEE project is using these activities to build a strong assessment portfolio system, which involves detailed analysis of student work and provides ways for the teacher to assess student progress. In addition to indicating that sequences of selected GEMS activities can be used to support the national standards, this project should also provide data on how well the GEMS activities selected conveyed the key concepts, through its assessment system and analysis of student work.

The School Community Mathematics Project (SCMP) 1990-1994, funded by the California Post secondary Education Commission (CPEC), Eisenhower Mathematics and Science Education State Grant Program: SCMP worked with the seven elementary schools of the Pittsburg Unified School District in Pittsburg, California to enhance mathematics teaching and improve the math curriculum taught in the district. Half of the units selected as the core curriculum were from the GEMS series or from activities that were later published as GEMS units. An important goal of the project was to utilize materials that addressed state and national science and mathematics standards. District K-5 teachers received eight full-day inservices on these units per year, seven on-site model lessons in their classroom, and instructional materials, and participation in education conferences, field trips, reunions, school-wide science/math nights and assembly programs. The evaluation component included attitude surveys, feedback forms, comment cards, classroom visits, student work (including mathematics journals), and teacher observations of student learning. The progress report and summary of evaluation data reflect significant improvement in teacher instructional practices, classroom math curriculum and student understanding of key concepts. Teachers also noted an improvement in attitudes toward science and mathematics. One principal noted an improvement of student math scores from the CTBS (California Test of Basic Skills). The success of the math project led to a similar 4-year science program, sponsored by Dow Chemical. A number of GEMS guides were selected for use in Grades K–5. Assessments were developed for each unit; training and materials were provided for grade level leaders. Evaluation for SCMP was conducted by Dr. Jan M. Goodman.

Study on the Learning Station Approach. In 1990, a Finnish science educator, Maati Erätuuli, and Dr. Cary Sneider conducted a systematic observation of families in a science discovery room. An observation instrument—a set of questions and ratings to be used by a trained observer—helped determine whether or not visitors read the cartoons and station signs, used the lab equipment as intended, and read the more extensive information available at each exhibit. The data was analyzed statistically. The most important contribution to the literature about science discovery rooms is that a majority of visitors did not manipulate the equipment randomly. Their actions at the exhibits showed they understood the instructions; and their expressions showed that they were interested in what they discovered. An article on this aspect was published in *Science Education* (see closing reference). Ten of the most popular exhibits were selected to become a GEMS exhibit guide, *Wizard's Lab.* These ten exhibits, along with the cartoon instructions, were among those included in the research study. GEMS also developed a *Shapes, Loops, and Images* exhibit guide, with tabletop exhibits on shapes, reflections, and topology. The success of these tabletop exhibits suggested they could be excellent classroom learning stations. When further testing revealed successful teacher experience with learning stations, we developed learning station GEMS teacher's guides, classroom-based rather than "exhibit guides." These include *Bubble Festival*, *Mystery Festival*, *Microscopic Explorations, Build It! Festival* and *Math Around the World.* The classroom learning station approach, because it allows students to proceed at their own pace and make their own discoveries, can be a particularly effective mode of presentation for activity-based science and mathematics.

Erätuuli, M. and Sneider, C: "The Experiences of Visitors in a Physics Discovery Room." *Science Education* 784 (4) (1990): 481-493.

Trial Testing. The development of every GEMS unit includes a thorough pilot testing by GEMS staff and field testing by classroom teachers nationwide. Following a pilot test in one local classroom, the teacher's guide is written and revised as a classroom lesson plan outlining the activities of the unit. This local trial version is sent, along with a kit of materials, to 24 local classroom teachers at multiple grade levels for the local field test. Teachers conduct every activity from the draft guide over 8 weeks and provide detailed written feedback and student work supporting its effectiveness. Teachers' written evaluations are often 12–16 pages long depending on the length of the unit. The responses are compiled, reviewed by the author/developer team, and then used to revise the draft for the GEMS National field test. The national field test is conducted with 24 teachers at 6 school sites across the country, again over a 2-month period. Feedback is again compiled, reviewed, and used to refine the final draft of the guide. The final draft is also sent to experts in the content fields of mathematics, science, and education to develop a high level of educational quality and scientific integrity. The GEMS testing and development process spans 18 months. This complex process provides concrete evidence of 1) student learning and information helpful in assessment of student progress and overall evaluation of educational effectiveness, and 2) correlation to learning goals outlined in national, state, and local science/math standards and guidelines. Published GEMS guides are revised frequently, based on continuing teacher feedback, scientific update, and new findings in science and mathematics educational research.

Barber, Jacqueline, "The Making of GEMS: Partners in Developing Curriculum, in Sussman, Art (editor) *Science Education Partnerships: Manual for Scientists and K–12 Teachers*, University of California, San Francisco, 1993, pages 125–129.

Standards-Based Recommendations: Several GEMS units are recommended in NSTA's *Pathways to the Science Standards* under the "Science as Inquiry" standard and many others are recommended under the other content standards. GEMS units are also recommended in the 1996 edition of the *Resources for Teaching Elementary School Science of the* NSRC (as well as the companion volume, *Resources for Teaching Middle School Science)* as they are "judged to be supportive of inquiry-based science teaching that fosters understanding of science concepts through hands-on student investigations." GEMS has also been featured in recent Eisenhower Clearinghouse publications and highlighted in the 1997 and earlier NSF National Science and Technology Week Resources Guides, posters, and related publications.

Lawrence Lowery (editor), *NSTA Pathways to the Science Standards*, Elementary School Edition, National Science Teacher's Association, Arlington, Virginia, 1997. GEMS guides are recommended under Science As Inquiry (page 42), Physical Science (pages 56, 57), Life Science (page 69), Earth and Space Science (page 78), and Science in Personal and Social Perspectives, page 100.

Resources for Teaching Elementary School Science, National Science Resources Center (NSRC), National Academy Press, Washington, 1996. Numerous GEMS units are recommended and described.

Resources for Teaching Middle School Science, National Science Resources Center (NSRC), National Academy Press, Washington, 1998. Many GEMS units are recommended and keyed to *NSES* standards

Cary Sneider, with Jacqueline Barber and Lincoln Bergman, *The Architecture of Reform, GEMS and National Standards,* GEMS Handbook, Lawrence Hall of Science, 1997.

GEMS Model Schools (or Districts): The Fall/Winter 1998 *GEMS Network News* newsletter included a survey entitled, “Are You A GEMS Model School?” (page 10, 11). Among the responses received were a master’s thesis by Mary Anne DeGrazia, a GEMS Associate who teaches at Creekside Middle School in Castro Valley, California. Her thesis concerns the development of a middle school science program using GEMS units and a three-year plan for its implementation, which is now under way. Strong emphasis is placed on the inquiry approach, supporting national standards, and actively involving teachers in evolving their own curriculum plans. DeGrazia states that teacher and student attitudes have been positively impacted by the transition to GEMS sequences. Mindy Hostick of Steiner Ranch Elementary, Leander ISD in Austin, Texas, described how her district has selected a large number of GEMS units, from grades K-5 and correlated them to the *NSES*, TEKS, and the district’s science objectives for each grade level. Cindy Lueckemeyer of Spring Independent School District, also in Texas, detailed a K–8 curriculum featuring 23 GEMS units, aligned to the district’s recommendations, as well as state and national standards. Similar responses were received from Salt Lake City, Utah; North Royalton, Ohio; Princeton, Missouri; York, South Carolina; Somerset, Massachusetts; Iowa City, Iowa; McLeod, Montana; Milwaukee, Wisconsin; and many other locations in California, Texas, and other states. All state that they have had great success presenting GEMS units and encouraging other teachers to make the transition to inquiry-based science teaching. While many of these responses came from individual teachers who have had some level of GEMS professional development, most were not directly associated with a GEMS Site or Center, so provide examples of the widespread independent usefulness that many teachers and districts find in GEMS units.

GEMS Sites and Centers: Other Evidence of Success: We have also gathered a great deal of information from the growth of our nationwide network of GEMS sites and centers. Over the past 10 years, GEMS has developed a strong network of over 15,000 educators nationwide who regularly use GEMS materials to meet the goals of their mathematics and science programs. Close to 1,500 of these educators are more highly trained GEMS Associates who not only use GEMS with students but primarily serve as teacher-educators and present professional development workshops, courses, and institutes to colleagues in district, county, state, and national settings. Many GEMS Associates work collaboratively through the more than 35 GEMS Centers/Sites across the country (see the descriptions of current GEMS Centers and Sites in enclosed recent issues of the *GEMS Network News*). These Associates have the important job of linking GEMS training to curriculum, student learning, and professional development needs of their area. In the process of articulating GEMS units to address local, state, and national standards and guidelines, these Associates are providing us with invaluable information on the educational effectiveness and success of the GEMS program. The following examples showcase the efforts of a few of many GEMS Associates at these sites and centers who use GEMS instructional materials and professional development approaches to help meet the needs of all students and teachers in their region:

• **Austin, Texas GEMS Site:** As Director of the Austin GEMS Site, Dr. Karen Ostlund has correlated every GEMS unit to the Texas Essential Knowledge and Skills (TEKS) for math and science, to the *NSES*, and to the TAAS tests (see for example the alignment of 8th grade science to GEMS units). Her work shows how the learning goals of GEMS strongly reflect standards set by the Texas State Department of Education as well as the *NSES* (see the Associates Column on pages 4-5 of the Fall/Winter 1997 *GEMS Network News.*) Dr. Ostlund conducts GEMS workshops for teachers in Texas and around the country and has recently developed a "Super Saturday" inservice program for the Austin region, co-sponsored by the University of Texas. Dr. Ostlund's Co-Director, Mimi Halferty, is also an active presenter of GEMS, and has used GEMS for many years in her classrooms of Kindergarten and 1st and 2nd graders. Over a 3.5 year period, Dr. Ostlund and Ms. Halferty have conducted over 35 days of inservice for 600 teachers, teacher educators and administrators across the state of Texas.

• **Madison, New Jersey GEMS Site:** Dr. Henry Gary is the GEMS Site Director and Director of the Science Education Center at Fairleigh Dickinson University. He reports that a number of districts in New Jersey have adopted GEMS units. Those public school districts intersect many cities including Plainfield, Edison, South Orange-Maplewood, Flemington, West New York, and Union City. These adoptions occurred following workshops he and other GEMS Associates conducted with teachers at the GEMS Site and school sites. They have received excellent feedback from teachers commenting on the effectiveness of the activities and how much the students gained from the experience. GEMS science units including *Moons of Jupiter*, *Discovering Density*, and *Color Analyzers* are being used as core program units to extend and enhance the existing science curricula.

• Los Angeles Unified School District, California GEMS Center: As the third largest public school district in the nation, LAUSD has established five district Mathematics/ Science/Technology Centers to serve the math and science education needs of its 650,000 students. These five centers are supported by a NSF Urban

Systemic Initiative. The East Los Angeles Center also serves as a GEMS Center providing GEMS training and materials to schools in their region, and the LAUSD GEMS Center Director is Anna Gaiter. The LAUSD is one of our most active sites, providing professional development to thousands of teachers in the past three years. The GEMS program has shown itself able to flexibly serve the diverse population, complex social issues, and linguistic diversity of the Los Angeles student population.

• **Seabrook, Texas GEMS Site:** Myra Luciano is one of the key GEMS Associates working through this site near Houston. She has many years of classroom experience and for the past 5 years has presented GEMS workshops to colleagues at district summer institutes and conferences. She is a leading mathematics and science education mentor for her school and received a grant in 1997 from the Partners in Education Foundation, a local philanthropic group, to implement *Build It! Festival* at her elementary school. She conducted both a 1997 performance-based evaluation of *Build It! Festival* which showed considerable improvement in recognition of shapes and spatial sense and a 1999 study of *Animal Defenses* which showed that students learned and retained concepts conveyed in the GEMS unit. Overall, Ms. Luciano continues to play an important role as a GEMS consultant in her region and has impacted thousands of educators through her model lessons and workshop presentations.

Program Costs, Impact, and Implementation

GEMS guides are relatively inexpensive, certainly one of the key factors in their accessibility to the individual teacher or school. They range in price from under $10 to several that are in the $30 or $40 range, with the average retail price approximately $15. Guides are distributed by Lawrence Hall of Science, through many science and math educational distributors, bookstores, catalogs, teacher supply stores, and other outlets. GEMS Leaders and Associates receive discounts, as do many distributors, including the National Science Teacher's Association (NSTA) and a national book trade distributor. For the first 14 years of the program, teachers and districts have gathered their own materials, although a number of school districts and GEMS Network Sites or Centers have made materials kits for GEMS units and established lending libraries for these kits. Official GEMS Kits, produced in partnership with Sargent-Welch, will start to become available in April 1999, with kits for 20 GEMS units planned by the start of 2000. Prices for these kits will be as reasonable as possible, with less complex kits under $75 and more complex kits $200 or less. Costs for GEMS professional development workshops and institutes varies, depending on length and other factors. Grant-supported awareness workshops have often been offered free or for a nominal fee. The 3-day GEMS Leader's or GEMS Associate's Workshops have been offered for under $400 per person, and both include a large number of GEMS guides and handbooks as part of the fee.

GEMS units and curriculum sequences are used annually in many thousands of classrooms in public and private schools, by a wide spectrum of teachers, ranging from those starting out to those extremely experienced with inquiry-based curricula. GEMS is also used in a wide variety of professional development experiences, by many University professors in methods courses and when assisting their local school districts, by scientists in partnership programs with schools, by corporate and foundation education personnel in establishing regional alliances for improvement of science and math education, and by leading presenters at regional and national math and science conferences, such as NSTA and NCTM. A network of GEMS Leaders and Associates helps implement the program nationwide**. Please see the enclosed GEMS newsletter for a listing of more than 35 Sites, directed by GEMS Associates, and feel free to contact any of them for more specific information.** These range from the Los Angeles Unified School District to Vero Beach, Florida; from an extensive network in Texas to Vancouver, Washington, from St. Louis and Kansas City, Missouri to Bemidji Minnesota and Port Huron, Michigan. Many sites are evolving areas of expertise; all offer professional development and regional support for teachers implementing reform in math and science education. GEMS staff and Site and Center Directors are also piloting real-time meetings on the Tapped-In Multi-User Virtual Environmental (MUVE) for educational exchange recently launched by the Stanford Research Institute and other groups. General GEMS information is provided there, as well as on the rapidly developing LHS website. GEMS is used in many diverse regions, and has been used successfully with students of differing racial and cultural backgrounds, girls and young women, and other groups historically underrepresented in math and science, with Navajo and other Native American students, English language learners of many nationalities, students facing learning or physical challenges, gifted students, etc. GEMS student sheets have been translated into Spanish. GEMS has also been used in after-school programs, at childcare centers, community centers, and at family events. Internationally, GEMS is used in Canada, Mexico (notably in Chiapas), other Central, South American and Caribbean nations, Australia, New Zealand, South Africa, Turkey, Spain, Finland, Denmark, and many other countries.

Due to the nature of the program, which is independently presented nationwide by many thousands of individual teachers each year, we do not have specific percentages of ethnic, racial, or gender participation. Based on our own testing histories, distribution of more than one million teacher's guides, workshop records, and reports from GEMS Leaders/Associates, we know that a minimum of 600,000 teachers and 8 million students have experienced GEMS, and that this includes highly diverse urban and rural populations and much linguistic diversity. The local and national testing processes include a wide multiplicity of students, teachers, and regions. Specific GEMS units have been used very successfully in classes for developmentally disabled or other special needs students, gifted programs, National Council of La Raza after-school education programs, at community center, PTA, and Parent's Day gatherings, in many less advantaged inner-city schools, as part of a rural distance learning project with interactive TV throughout the Northwest, in home schooling programs—in almost every venue imaginable. The highly accessible and flexible nature of the GEMS materials has contributed to their effective and rapidly expanding use nationally and internationally.

All GEMS units and the handbook series pay careful attention to describing the conditions and resources involved in presenting the activity in the classroom and/or implementing GEMS on a school or district level. On a unit level, there are detailed instructions in the "What You Need" and "Getting Ready" sections to fully advise teachers of easy-to-obtain materials and preparation steps needed in order to present the activities. The *GEMS Teacher's Handbook and GEMS Leader's Handbook* include general advice on the transition to and presentation of activity-based science and more specific ideas for professional development initiatives, while the *Architecture of Reform* provides a basic outline of how one might undertake curriculum planning and evolve a "local plan" for the implementation of science education reform (pages 57–65). At the most basic level, presentation of a GEMS unit requires a teacher's guide and acquisition of the needed materials. The *GEMS Kit Builder's Handbook* provides full materials lists for GEMS guides, and has been helpful to those teachers, districts, and sites that build and maintain kits. Other users can soon take advantage of the more costly but time efficient purchase of kits. The availability of GEMS Kits is likely to expand the user base. Prices for GEMS Kits are planned to be less expensive than many other kits.

The educational effects of the GEMS program are definitely beneficial for students and teachers when costs in time and money are considered. As a supplementary program, GEMS is often used in a time-efficient manner by teachers, combining relatively succinct GEMS units with textbooks or other programs. All activity-based programs require some materials gathering and advanced preparation. Some GEMS units are more preparation-intensive than others, but these, including many of the chemistry units as well as the very involving *Mystery Festival*, have high benefits in student interest, motivation, and learning. Preparation checklists are often provided to help teachers organize the tasks. The tradeoffs involved are carefully explained to the teacher and numerous tips are provided to streamline preparation, gain assistance from student teams, parents, or aides, and obtain donations from the community. Several GEMS handbooks, especially the "1001 Ideas" section of the *GEMS Leader's Handbook* (pages 33–76) contain suggestions and helpful hints for teachers to save time and expense and yet present activity-based science in highly effective and efficient ways.

Under the heading "science is for all students" the *NSES* strongly advocate that all students should be able to experience and benefit from excellent science education. *The Architecture of Reform* handbook seconds this important part of the "common vision." GEMS has been grounded in this goal since its inception, in regard to multicultural and gender equity issues, and also due to a commitment to activities that can be presented by all teachers, including those without specialized math and science background, while utilizing accessible and economical materials. The respectful and non-condescending tone of the guides is often cited as one reason for the appeal to teachers. In the text, editorial care is taken to promote respect for diverse cultures and avoid the use of sexist or any other prejudicial language. A number of examples of guides that reflect cultural diversity are noted earlier. *On Sandy Shores* and several upcoming units *(Only One Ocean* and *Ocean Currents*) adapt activity structures designed to assist students who are English language learners in both acquiring language and learning science. **GEMS student data sheets have been translated into Spanish to allow more effective**

presentation of activities in settings where such translations are needed. The photographs in GEMS units, cover designs, literature connections, resources, and poems are selected with attention to representing the wide spectrum of students and teachers. The cover of *Height-O-Meters*, for example, shows a young woman student in a wheelchair taking active part in an outdoor measuring activity. *Stories in Stone* features selections from Chilean poet Pablo Neruda while *River Cutters* includes a famous poem by African-American poet Langston Hughes. The vast majority of GEMS guides include photographs depicting a high proportion of girls/young women taking active roles, and there is high representation of African-American, Latin, Asian, and other non-white students. GEMS has also consulted with others as needed on issues of cultural sensitivity. This was of particular importance to the non-stereotypical portrayal of Native Americans in the *Investigating Artifacts* guide. In issues of curriculum construction and pedagogy, GEMS has been guided by the understanding that cooperative learning, manifested in all GEMS units, and activity-based learning in general, can be facilitators of equity and equality of access.

Special Considerations and Conclusion

There is ample evidence of the widespread distribution of GEMS and its active and continued use by many thousands of teachers, with more reached each month as leadership and awareness workshops are held nationwide, testing for new units proceeds, more sites and centers are launched, as GEMS Kits become available, and as teachers hear about a new or classic unit and contact GEMS. The scale of GEMS implementation in many different settings suggests significant impact, scope, and importance. These units are solidly grounded in inquiry-based pedagogy and provide teachers with creative, accessible, innovative, and highly practical knowledge of effective teaching and learning. In addition to all the elements of scientific (and mathematical) content, learning, standards, and assessment described in this submission, there is a strong emphasis on teamwork and cooperative learning. GEMS units also extend into many other disciplines, including writing and literature, art, and diverse cultures, and as such contribute to the formation of the "whole student" while helping students understand the connections and underlying conceptual frameworks of many branches of human knowledge. Research studies indicate that specific GEMS units increase student understanding of key content and process skills. Specific evidence of positive differences in student learning will be considered in later sections of this submission. Information derived from teacher and student feedback during testing, unsolicited teacher anecdotes and letters, student work sent in during testing or gathered for assessment, evaluation studies of programs that used GEMS units, and classroom pilot testing of our assessment tasks—all testify to a positive impact on student attitudes toward science and math. In addition, the implementation of a variety of flexible GEMS curriculum sequences through GEMS regional sites, as well as numerous other school districts, provides not only a strong indication of scope and importance, but a promising framework for the development of independent research studies to demonstrate the effectiveness of GEMS units. As we enter an era of increasing emphasis on the achievement of national standards and as curricula are increasingly evaluated for their effectiveness, it is our intention to undertake such studies, in a variety of forms. Within this context, information gained from such studies will be carefully applied to the development of new units and the revision of existing ones.

The rapid expansion of the GEMS Network, and the training of more than 15,000 GEMS Leaders and close to 1,500 GEMS Associates suggests that the GEMS program is an extremely fertile field for the spread of effective inquiry-based teaching practices and current approaches to professional development. GEMS staff keep themselves apprised of current professional development approaches and have incorporated these ideas into advanced Associates and Associates II workshops. As *The Architecture of Reform* points out, the "one shot" workshop model is not adequate and more sustained models are required (pages 63-64). Instructional materials can play a critical role in teacher change—GEMS units are "teacher's guides," and they provide step-by-step instructions, pedagogical explanations, logistical suggestions, frameworks to elicit and guide discussions, ways to analyze data and findings, background information, and assessments—all to enable all teachers to present effective inquiry-based math and science. As such, GEMS units can and do serve as exemplars in methods and preservice courses, helping prepare new teachers and transform practices of more traditional teachers. GEMS units are often presented independently at national and regional conferences, as part of district educational presentations, and at teacher-education events of all kinds. In addition, the GEMS Handbook Series serves as an accessible resource for teachers. For example, the *GEMS Teacher's Handbook* and *GEMS Leader's Handbook* include summaries of the inquiry-based, guided-discovery approach, along with emphasis on questioning strategies, collaborative work, the learning cycle, and issues associated with transition from a more traditional approach to an activity-based curriculum. The literature handbook *(Once Upon A GEMS Guide*) connects science and literature, reaching additional teachers. Many handbooks include information that relates to inquiry-based science in general, not only to GEMS. In fact, GEMS units have also served, in many regions, as a successful and accessible catalyst for teachers to work towards gaining confidence in presentation of other well-known inquiry-based programs of a more comprehensive nature (such as FOSS, Insights, or STC). This is a useful function, given the uneven nature of reform from state to state and region to region. All this suggests that GEMS makes significant contributions to teachers' knowledge of effective teaching and learning. GEMS is also actively involved in a series of parent education programs, some of which are aimed at improving teacher relationships with parents and the community, thus also contributing to more effective teaching and learning.

GEMS is designed to improve learning for *all* students—to reach the widest and most diverse section of students (and teachers) possible. We have much information from trial-test teachers, letters, and other comment as to the ability of GEMS to meet special needs of students with learning or physical challenges, as well as under-served and underrepresented groups. We are moved by stories such as one in the "Galaxy Classroom" evaluation, where the activities moved a student who had never before spoken in class to make his first comments. The engaging, science-as-questioning, investigating-more-deeply quality of GEMS also means that special learning needs of students whose interests and talents go beyond core math or science education, including gifted students and students engaged in home schooling or independent study, are well served by GEMS units. A deep commitment to all students is represented in the language and presentation of GEMS, as is a genuine sense of discovery and investigation—qualities with appeal to a wide range and multiplicity of teachers and students. There is always room for improvement and, as we work alongside many other excellent programs, all of us have much to learn. We hope the GEMS program will make its own modest contribution to the many future transformations and innovations in science education that loom as we enter the 21st century.