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FINAL RESULTS OF SPACE EXPOSED EXPERIMENT DEVELOPED FOR STUDENTS

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SUMMARY

"The SEEDS experiment gave students ownership in their future of space study. They felt important; they felt their information was of value." This comment from an elementary teacher, is representative of responses from many of the nearly 8,000 educators who submitted students' data for the SEEDS (Space Exposed Experiment Developed for Students) final report. SEEDS was a cooperative endeavor of NASA Headquarters, the NASA Langley Research Center, and the George W. Park Seed Company. Approximately 132,000 SEEDS kits containing Rutger's tomato seeds that had flown on LDEF, as well as similar seeds that had been stored in a climate-controlled warehouse for the same time period, were sent to schools in every state and 30 foreign countries. Student researchers from kindergarten through university compared germination and growth characteristics of the space-exposed and Earth-based seeds and returned data to NASA for analysis. Important scientific information was gained as students reported very little difference between the two seed groups.

INTRODUCTION

NASA, sharing a national concern for the declining numbers of young people opting for careers in science and engineering, has developed a number of programs to stimulate student interest in an effort to increase enrollment in upper-level pre-college science and mathematics courses. Realizing attitudes toward science and mathematics are formed prior to secondary education and knowing students learn best when they are active participants, the SEEDS project was conceived with the following objectives:

1. To involve a very large number of students in a national project designed to generate interest in science and related disciplines.

2. To offer students from elementary through university level an opportunity to participate in first-hand experiences with materials flown in space.

3. To provide the opportunity for sharing results among all participants.

BACKGROUND

Several brainstorming sessions resulted in the decision to fly 12.5 million Rutger's tomato seeds on the LDEF (Long Duration Exposure Facility). The seeds were packed into five aluminum canisters which were sealed at 101kPa (14.7 psi) pressure/atmospheric gases and 20 percent relative humidity. Four layers of seeds (A, B, C, D) were placed in each canister, with each layer confined by Dacron bags. Layer A was near the exterior of the satellite. A passive maximum temperature thermometer was placed in each canister and thermoluminescent passive dosimeters were placed between the layers of seeds. The

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canisters were fastened inside a tray which was loaded onto the LDEF. An equal number of seeds was placed in Park Seed Company's controlled environment of 21°C, 101kPa pressure, and 20 percent relative humidity.

The LDEF was launched April 984, aboard Space Shuttle Challenger, Mission 41-C, and deployed one day after launch for what was expected to be a one-year mission. Retrieved in January 1990, by the crew of Columbia during Mission STS-32, the SEEDS tray was the first experiment removed from the LDEF. The Park Seed Company assembled and distributed the SEEDS kits. Grades 5-9 kits contained an instruction manual, an activity book, a data collection booklet, a press release, a letter from the U. S. Department of Agriculture regarding the safeness of experimenting with the seeds, and two packets of fifty seeds; one packet of space-exposed seeds from throughout the four layers from a single canister and one packet of Earth-based seeds. The high school kit contained the written materials and three packets of seeds; one packet of 50 Earth-based seeds, one packet of 25 seeds from layers A and B and another packet of 25 seeds from layers C and D from the same canister. The college kit was similar, but contained five packets of seeds; 50 Earth-based seeds and four packets of 25 seeds from each layer within a canister.

Distribution of over 132,000 SEEDS kits to 64,000 teachers representing 40,000 classrooms and 3.3 million kindergarten through university students was a good indication that objectives 1 and 2 would be achieved. The kit originally intended for grades 5-9 was frequently requested and distributed to grades kindergarten through four. Seventy-seven percent of all data returned came from grades K-9; twenty percent was from high schools, with the remaining three percent from higher education. Most participants used an integrated approach, emphasizing the interdependence of the various disciplines students study each year. A comment from an elementary teacher perhaps best sums up the impact upon the total school curricula. "This project jibed well with our science curriculum and as part of math lessons, it generated many useful graphs. Since we do a great deal of writing, the students also wrote wonderful stories--from factual journals to imaginative fiction about the aliens in the seeds! I enjoyed the SEEDS project because it was *REAL* -- not the teachers and not NASA knew the results! That is so unlike the rest of our mundane science experiments where we *contrive* projects to prove what we *already* know. Your contribution makes both teaching and learning more exciting and relevant." Objective 3 was achieved as the summary report, *SEEDS: A Celebration of Science*, was sent to each data respondent. Schools returning data also received a Certificate of Participation. Figures 1-12 illustrate the phases of the SEEDS Experiment.

RESULTS AND DISCUSSION

The primary value of the SEEDS project was students' involvement in the scientific process as they observed, measured, classified, experimented, interpreted, communicated, developed models and practiced safety. The figures at the end of this paper focus on students' development of the science process skills.While many reports indicated Earth-based seeds germinated more quickly than space-exposed seeds, overall data analysis suggests space-exposed seeds did germinate at a slightly faster rate. This difference was more evident as data among the three levels were compared and correlations made between germination time and germination media. Those students using moistened paper towels were able to observe radicle emergence at an earlier stage than those covering seeds with soil. Variations in reported observations increased as growth proceeded. Reports ranged from differences in plant size, shape, color, odor, leaf position, and stem thickness to resistance to pests. Many students reported Earth-based plants being eaten by deer, birds, rabbits, gerbils, moose, ferrets, ants, and cockroaches while the space-exposed counterparts were untouched or only slightly nibbled. Individual reports of space-exposed plant variations included stunted plants, plants that added a leaf instead of the usual flower at the end of the flower frond, and fruit produced from a flower with a variegated calyx bearing seeds producing albino plants, while fruit from a green calyxed flower from the same plant bore seeds producing green plants.

Young student researchers, influenced by many hours of science-fiction treatment through print, audio and video media were eager in their search for mutations. Some were disappointed because the

Rutger's California Supreme tomato is relatively genetically stable. Radiation data indicated layer A within each canister received approximately 725 rads, while layer D received 350 rads. Students asked lots of questions when their data supported variation in both the Earth-based seeds and the space-exposed seeds. Their questioning increased when the media published articles warning of the possibility of poisonous fruit from the space-exposed seeds. This pursuit generated a greater understanding of genetics and radiation, two topics typically stimulating a number of misconceptions. The development of critical-thinking skills was enhanced. SEEDS allowed for concrete experiences with abstract concepts and provided many opportunities for open-ended discussions and experimentation.

There was much evidence of the use of problem-solving skills reported from all grade levels. Many schools had to acquire the materials and equipment necessary to successfully participate in the SEEDS project. Many recycled materials were used as germination and growth containers. Sophisticated problem solving included the assembly of a robotic watering system by an elementary class and the development of hydroponic growth systems by several secondary classes.

Creativity was abundant whether classes chose to complete the NASA-suggested experiment or to design their own experiments to compare various characteristics of the space-exposed and Earth-based seeds. In almost all participating schools, creativity was manifested in the selection of sites for growing a very large number of tomato plants. On-site school gardens ranged from greenhouses to outdoor classrooms, newly tilled gardens to trenches, and various-sized containers to simply planting in bags of potting soil. Off-site gardens ranged from large fields to containers on patios or in windows of high-rise apartments.

Community involvement was an important aspect and pleasant outcome of the SEEDS project. Many materials and hours of labor were donated by local businesses, organizations and families; gardening expertise was provided by horticulturists, experienced gardeners, and often by grandparents and other older citizens. High school biology and agriculture classes worked with elementary classes. Partnerships were formed that will endure far beyond the completion of SEEDS.

Tables 1--4 at the end of this paper represent the data of many novice as well as a few seasoned researchers. Interpretation must include an understanding of and appreciation for the fact that most of the data was returned by novices. One teacher summarized it well by stating, "Measurements were truly student done--with misunderstandings and errors no doubt abundant."

Growth data, analyzed at the end of 56 days, indicated the initially faster growth in the space-exposed group began leveling out after four weeks. Correlations made between growth data and the growing environment indicated that plants grown indoors with limited sunlight or under artificial lights were weak-stemmed and spindly. Students were sometimes hampered in experimental efforts because of requirements that lights and heating be turned off when school was not in session. Data collection was often incomplete due to problems encountered when plants were undertended, overtended, measured, transplanted and transported. One secondary teacher noted, "The radiation above the atmosphere over a period of six years is negligible when compared to the dangers of a small classroom where 100 students come and go and check and water plants."

Secondary and college students devised experiments beyond those suggested by NASA. Bacterial studies of seed coats of space-exposed and Earth-based seeds revealed several species of Bacillus as well as a lactose fermenting bacteria. Unidentified fungi species were found on tested seeds. No differences were found in pH between fruits produced from space-exposed and Earth-based seeds. Space-exposed plants performed normally in tests of phototropism, geotropism, tissue culturing, and seed weight. Chromatography tests indicated space-exposed plants had greater levels of chlorophylls and carotenes than Earth-based plants. Tests found that light absorbence was greater in extracts made from space-exposed plant tissues. Results from laser-induced fluorescent spectroscopy led one team of researchers to conclude that space-exposed seeds exhibited premature chlorophyll development. They suggested this might partially explain the rapid initial growth of the space seedlings.

A secondary teacher reported, "We learned through the process that science is not easy. Many experiments were done to try to increase our chances of finding something new. If nature has it that nothing new is obtained, we do not consider it a failure. We consider ourselves one step closer in our search for information."

Student researchers concluded that space may be a safe place for long-term storage of seeds from many of Earth's endangered plants, as well as seeds from plants upon which the world population depends for food. In space, the seeds would be secure from unpredictable environmental factors on Earth.

Almost one-half of the participants returning data booklets indicated they would continue the SEEDS project with studies of second and subsequent generations. A need still exists in this nation for students at all levels to become involved in relevant, meaningful science activities. A parent wrote, "Our children were eager NASA scientists, fascinated with the concept of 'space' tomatoes, and were rewarded not only by their satisfaction coming from the completion of an independent scientific search, but also by the realization of working on a national project with *unknown* results. They felt part of something *really* important, and had an introduction to scientific methodology as well. Thank you for this unique and wonderful opportunity! You have provided the children with a special and well-designed experience which they'll always remember."

LDEF-USERS CHALLENGE

Scientists and engineers participating in LDEF research have an opportunity to become active in science education. An elementary teacher wrote, "The students felt important participating in what we felt would help make future decisions in space." Capitalize on this sense of contribution. Help relate the value of their research to the Space Station, Mission to Mars, Return to the Moon and other NASA projects. Volunteer to meet with classes and science and engineering clubs to discuss career opportunities and the necessary academic preparation. Serve as tutors, mentors and role models. Encourage female and minority students to enter science-related careers. Regardless of grade level, inform students about what they can do today to prepare themselves for a successful future. Give students examples in their everyday lives of applications and outcomes of a particular area of science or engineering. Offer to assist teachers with curriculum planning. Volunteer for eight hours a month to work with a local school. Give students an opportunity to associate science with a real person!

ACKNOWLEDGMENTS

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REFERENCES

1. Melton, Bob: *SEEDS: A Celebration of Science*, NASA EP-281, 1991.

Table 1. Summary Data: All Grade Levels

Space-exposed, Across All Canisters and Layers

	Number reporting	Mean	Std. Dev.	Min.	Max.
Germination rate: percent of seeds germinated 14 days after planting	7931	66.3	23.3	1.0	100.0
Average number of days required for germination within 14 days after planting	7288	8.4	2.6	1.0	14.0
Number of plants measured	4420	18.1	12.5	1.0	88.0
Average height (cm) at 56 days	4679	21.2	9.7	8.0	38.0
Average width (cm) at 56 days	4208	12.0	4.4	4.0	16.0
Flowering rate: percent of plants producing flowers	2118	73.4	34.4	1.0	100.0
Average number of days to first flower within 56 days	538	46.7	8.2	28.0	56.0
Percent of plants producing fruit	1849	74.6	34.2	1.0	100.0
Average number of days from planting until first fruit formed on plant	1621	94.3	25.5	35.0	150.0

Earth-based

	Number reporting	Mean	Std. Dev.	Min.	Max.
Germination rate: percent of seeds germinated 14 days after planting	7854	64.6	23.5	1.0	100.0
Average number of days required for germination within 14 days after planting	7281	8.5	2.7	1.0	14.0
Number of plants measured	4414	18.6	13.3	1.0	99.0
Average height (cm) at 56 days	4600	20.9	9.7	8.0	38.0
Average width (cm) at 56 days	4160	11.9	4.4	4.0	16.0
Flowering rate: percent of plants producing flowers	2106	72.3	34.9	1.0	100.0
Average number of days to first flower within 56 days	524	46.9	8.5	28.0	56.0
Percent of plants producing fruit	1773	76.1	33.0	1.0	100.0
Average number of days from planting until first fruit formed on plant	1570	94.4	25.8	35.0	150.0

Table 2. Summary Data: Grades K-9

Space-exposed, Across All Canisters and Layers

	Number reporting	Mean	Std. Dev.	Min.	Max.
Germination rate: percent of seeds germinated 14 days after planting	6157	65.8	23.9	1.0	100.0
Average number of days required for germination within 14 days after planting	5717	8.4	2.6	1.0	14.0
Number of plants measured	3459	19.1	12.9	1.0	83.0
Average height (cm) at 56 days	3684	20.9	9.7	8.0	38.0
Average width (cm) at 56 days	3273	11.9	4.4	4.0	16.0
Flowering rate: percent of plants producing flowers	1726	72.5	34.9	1.0	100.0
Average number of days to first flower within 56 days	396	46.6	8.5	28.0	56.0
Percent of plants producing fruit	1472	72.8	35.3	1.0	100.0
Average number of days from planting until first fruit formed on plant	1295	95.2	25.5	35.0	150.0

Earth-based

	Number reporting	Mean	Std. Dev.	Min.	Max.
Germination rate: percent of seeds germinated 14 days after planting	6104	64.0	23.9	1.0	100.0
Average number of days required for germination within 14 days after planting	5731	8.6	2.7	1.0	14.0
Number of plants measured	3478	18.5	12.8	1.0	90.0
Average height (cm) at 56 days	3615	20.6	9.6	8.0	38.0
Average width (cm) at 56 days	3251	11.8	4.4	4.0	16.0
Flowering rate: percent of plants producing flowers	1736	70.9	35.7	1.0	100.0
Average number of days to first flower within 56 days	385	46.7	8.7	28.0	56.0
Percent of plants producing fruit	1416	74.2	34.1	1.0	100.0
Average number of days from planting until first fruit formed on plant	1268	95.0	25.8	35.0	150.0

Table 3. Summary Data: Grades 10-12

Space-exposed, Across All Canisters and Layers

	Number reporting	Mean	Std. Dev.	Min.	Max.
Germination rate: percent of seeds germinated 14 days after planting	1494	67.4	20.7	1.0	100.0
Average number of days required for germination within 14 days after planting	1335	8.1	2.6	1.0	14.0
Number of plants measured	816	14.9	10.7	1.0	88.0
Average height (cm) at 56 days	843	21.6	9.6	8.0	38.0
Average width (cm) at 56 days	798	12.3	4.3	4.0	16.0
Flowering rate: percent of plants producing flowers	342	79.3	30.5	1.0	100.0
Average number of days to first flower within 56 days	126	47.3	7.3	29.0	56.0
Percent of plants producing fruit	298	81.1	28.8	1.0	100.0
Average number of days from planting until first fruit formed on plant	260	91.5	25.1	36.0	150.0

Earth-based

	Number reporting	Mean	Std. Dev.	Min.	Max.
Germination rate: percent of seeds germinated 14 days after planting	1481	66.1	22.4	1.0	100.0
Average number of days required for germination within 14 days after planting	1328	8.3	2.7	1.0	14.0
Number of plants measured	795	19.2	14.8	1.0	99.0
Average height (cm) at 56 days	837	21.5	9.7	8.0	38.0
Average width (cm) at 56 days	777	12.5	4.3	4.0	16.0
Flowering rate: percent of plants producing flowers	328	80.2	30.1	1.0	100.0
Average number of days to first flower within 56 days	125	47.6	7.9	28.0	56.0
Percent of plants producing fruit	287	82.6	27.6	1.0	100.0
Average number of days from planting until first fruit formed on plant	244	92.2	26.2	35.0	150.0

Table 4. Summary Data: College

Space-exposed, Across All Canisters and Layers

	Number reporting	Mean	Std. Dev.	Min.	Max.
Germination rate: percent of seeds germinated 14 days after planting	280	71.1	19.8	2.0	100.0
Average number of days required for germination within 14 days after planting	236	8.1	2.4	2.3	14.0
Number of plants measured	145	12.1	8.6	1.0	70.8
Average height (cm)	152	25.0	9.7	8.0	38.0
Average width (cm)	137	14.1	3.2	4.0	16.0
Flowering rate: percent of plants producing flowers	50	63.7	36.2	1.0	100.0
Average number of days to first flower	16	46.9	8.2	30.0	56.0
Percent of plants producing fruit	79	82.6	27.6	5.3	100.0
Average number of days from planting until first fruit formed on plant	66	89.9	24.6	38.5	150.0

Earth-based

	Number reporting	Mean	Std. Dev.	Min.	Max.
Germination rate: percent of seeds germinated 14 days after planting	269	69.8	21.5	4.0	100.0
Average number of days required for germination within 14 days after planting	222	8.1	2.5	2.0	14.0
Number of plants measured	141	18.1	16.8	1.0	96.0
Average height (cm)	148	25.0	9.9	8.0	38.0
Average width (cm)	132	14.1	3.3	4.0	16.0
Flowering rate: percent of plants producing flowers	42	69.5	34.1	2.0	100.0
Average number of days to first flower	14	47.2	6.9	34.0	56.0
Percent of plants producing fruit	70	87.2	23.9	10.0	100.0
Average number of days from planting until first fruit formed on plant	58	89.6	22.6	40.0	137.0

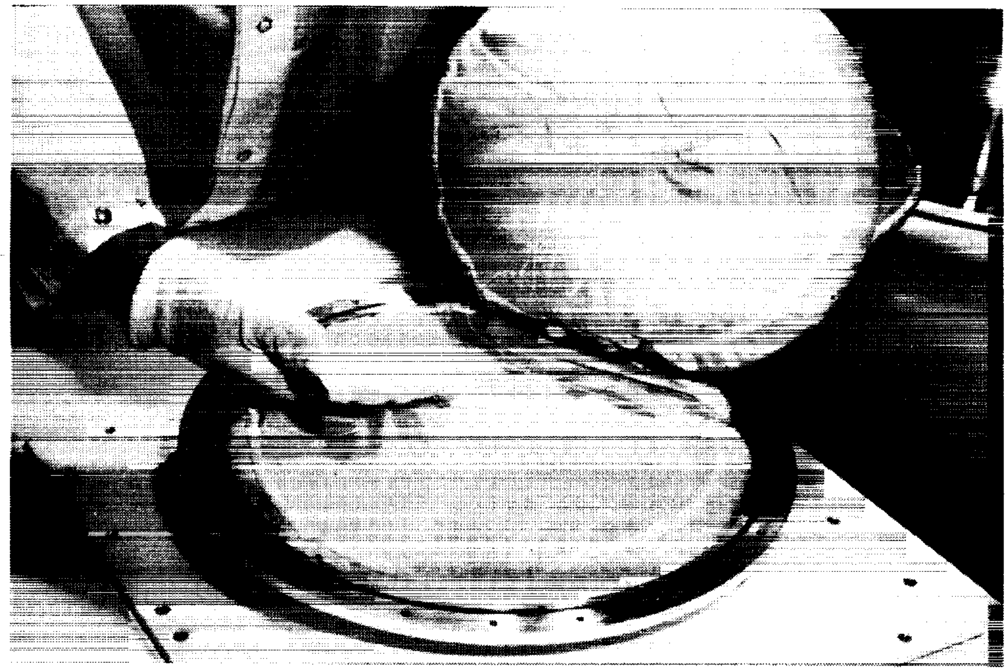

Figure 1. Layering seeds into canister.

Figure 2. Securing canisters into tray.

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Figure 3. Announcing SEEDS project to community.

Figure 4. Transplanting seedlings.

Figure 5. Transforming playground into tomato garden.

Figure 6. Observing and measuring.

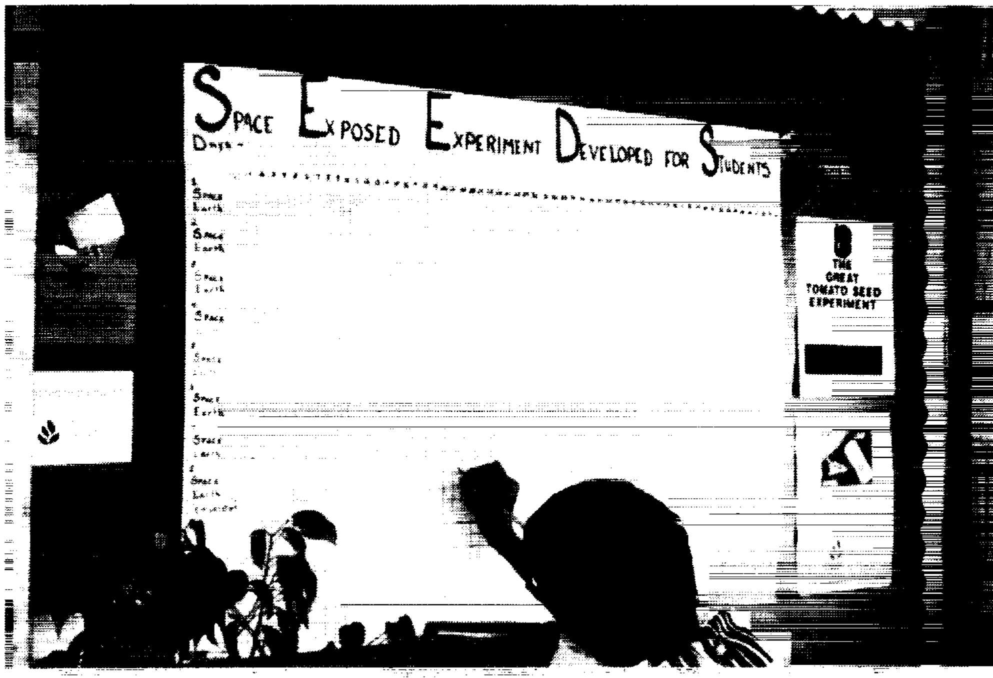

Figure 7. Recording data.

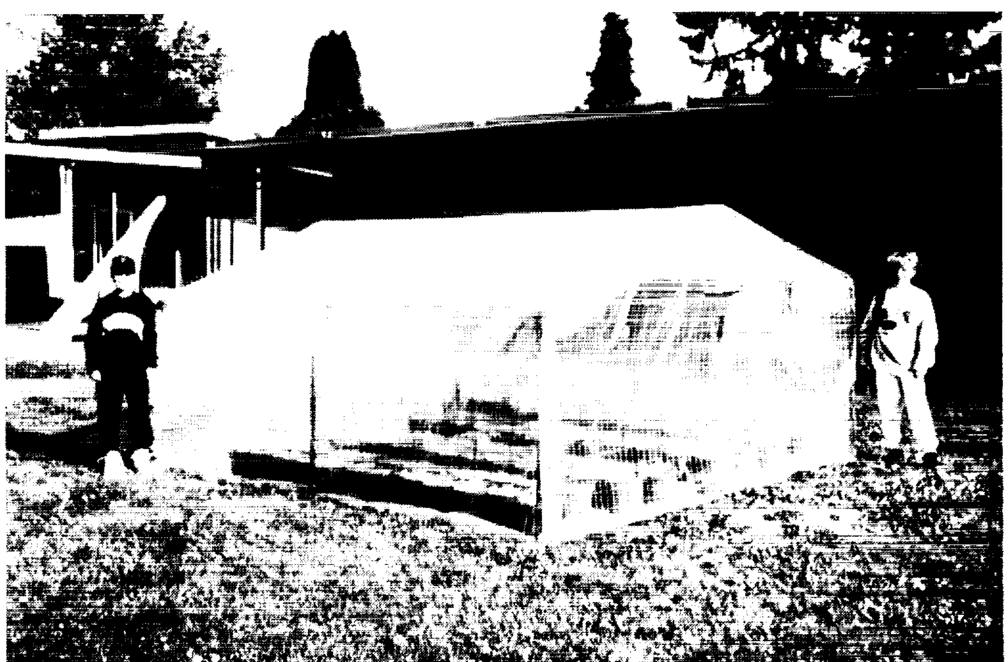

Figure 8. Developing short-term solution for problem.

Figure 9. "Adopted" plants taken home.

Figure 10. Removing seeds for second generation studies.

Figure 11. Displaying pride in involvement.

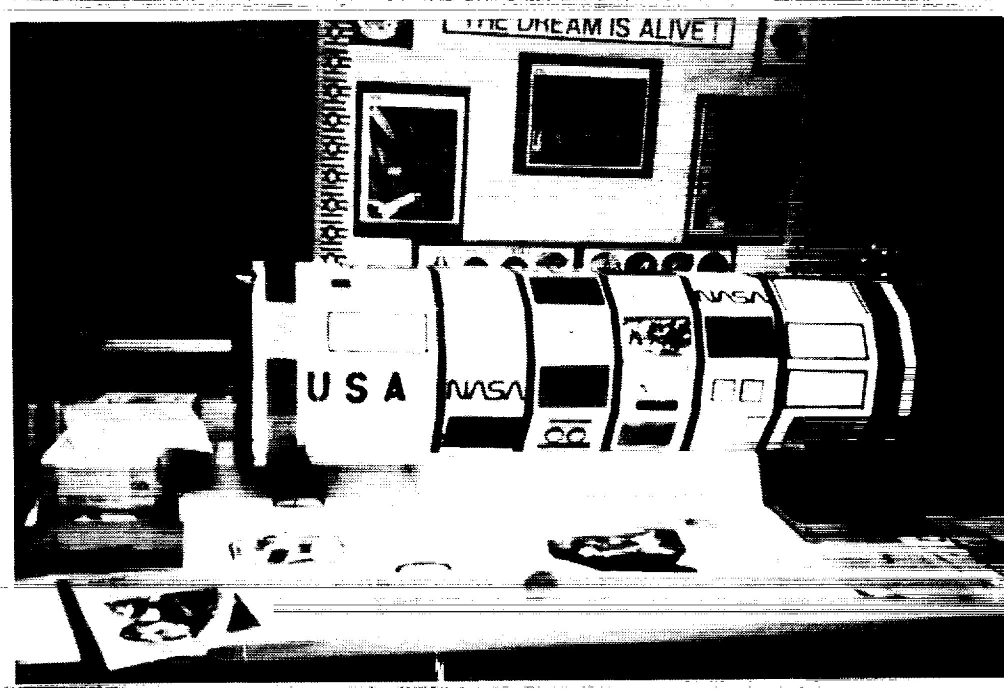

Figure 12. Model building.