Mars Rover Models -- A Program to Enrich Teaching Space Science, Planetary Exploration and Robotics in Elementary and Middle School

Edgar A. Bering, III[*], John Ramsey[†], and Brenda S. Boyko[‡]
University of Houston, Houston, Texas, 77204

Holly Smith[§]
Spring Branch Independent School District, Houston, Texas, 77055

Sandy Peck[¶]
Seabrook Intermediate School, CCISD, Seabrook, Texas 77586

and

William H. Arceneaux[#]
Lyndon B. Johnson Space Center, NASA, Houston, TX 77058

The present aerospace engineering and science workforce is ageing. It is not clear that the US education system will produce enough qualified replacements to meet the need in the near future. Unfortunately, by the time many students get to high school, it is often too late to get them pointed toward an engineering or science career. Since some college programs require 6 units of high school mathematics for admission, students need to begin consciously preparing for a science or engineering curriculum as early as 6th or 7th grade. The challenge for educators is to convince elementary school students that science and engineering are exciting, relevant and accessible career paths. This paper describes a program designed to help provide some excitement and relevance. It is based on the task of developing a mobile robot or "Rover" to explore the surface of Mars. There are two components to the program, a curriculum unit and a contest. The curriculum unit is structured as a 6-week planetary science unit for elementary school (grades 3-5). It can also be used as a curriculum unit, enrichment program or extracurricular activity in grades 6-8 by increasing the expected level of scientific sophistication in the mission design. The second component is a citywide competition to select the most outstanding models that is held annually at a local college or University.

I. Introduction

THE readers and audience of this paper are unlikely to recall a time when they, personally, did not find science and engineering to be exciting, compelling and consuming objects of our intellectual passion. For all of us, fascination with airplanes, rockets and the way things work have motivated us and defined who we are since very early in our lives. Unfortunately, far too few of today's young people have been inspired by their teachers and mentors to dream the dream of building a bigger, faster rocket to Mars or designing the next generation of airliner or fighter plane. It is not the purpose of this paper to document this fact. It is indisputable that the shortage of American children that enter college intending to major in science or engineering is becoming a major long term

[*] Professor, Physics and ECE, 617 Science and Research I/PHYS 5005, Associate Fellow.
[†] Associate Professor, Curriculum and Instruction, 256 Farish Hall/ CUIN 5027.
[‡] Project Director, Division of Research Initiatives, 316 E. Cullen/RIPM 2015, Member.
[§] Technology Improvement Specialist, Dept. of Instructional Technology, 9016 Westview Dr., A100.
[¶] Science Magnet Program Liaison, Seabrook I.S., CCISD, 2401 East Meyer Rd., Educator Member
[#] Spacecraft Integration Engineer, JSC/NASA, Code EX3, Associate Fellow

threat to the future of the American economy. This problem is deep-seated in our national culture, and will not yield to single "silver-bullet" solutions. The critical problem is that the pipeline has already emptied before the students arrive in University. They have made curriculum decisions in middle school and high school that leave them unable to major in science or engineering.

The purpose of this paper is to describe one effort to make a contribution to solving this problem. The heart of the issue is that far too many students are experiencing science in elementary and middle school in ways that convince them that science and engineering are boring, incomprehensible, irrelevant, and much too hard for them to understand. Ultimately, this problem can only be solved one teacher at a time. However, what organizations such as the AIAA can do is organize and provide enrichment programs and curriculum units that make engineering come alive for kids. All of us know that engineering professionals get paid to spend their time solving really fun puzzles and playing with extremely neat toys. It should not be as hard as it is to get that information across to kids. This paper describes an enrichment program designed to try and help solve this problem. It is based on the problem of prototyping a mobile robot or "Rover" to explore the surface of Mars. There are two parts to the program, a curriculum element and a competition. The curriculum element is structured as a 6-week planetary science unit for elementary school (grades 3-5). It can also be used as an enrichment program or extracurricular activity in grades 6-8 by increasing the expected level of scientific sophistication in the mission design, and adding more detailed written reports to the end product. The second part is a wide-area contest to select the most outstanding models that is held annually at a local college or University.

II. Program Description

Primary (Grades 3-5) and middle school (Grades 6-8) students interested in science and engineering design and build of a model of a Mars Rover (see Figure 1) to carry out a specific science mission on the surface of Mars. The students build the models as part of a 6-week fall semester classroom-learning or homework project on Mars. The students are given design criteria for a rover, and are required to do basic research on Mars that will determine the operational objectives and structural features of their rover. This module may be used as part of a class studying general science, earth science, solar system astronomy or robotics or as a multi-disciplinary unit for a gifted and talented program. A written report on the science objectives and design features of the Rover is required. As the grade level goes up, the expected length and sophistication of the paper increases. The program includes specific learning objectives in research skills, language arts (reading scientific literature, preparing a verbal presentation and writing a report), mathematics, science and engineering.

Figure 1. Contestant in the 2004 Mars Rover competition shows off her entry.

The models are supposed to be mock-ups, constructed at a minimal cost (estimated cost of less than $10-$25) of mostly found objects and simple art supplies. If desired, teachers may supply students with a low cost ($10) solar powered or ($25) radio controlled car kit to serve as the chassis. Solar powered, RC, and free-form (unpowered) models compete separately. The number of entries that can be accepted is determined by the size of the hall available for the contest. In Houston, we have space for ~150 models to be displayed and judged. Therefore, entries will be limited to the first 50 schools to enter, with 3 models allowed per school. Schools are encouraged to have entire grades participate. Youth groups such as Scouts and YMCA groups are also invited to participate. Pictures and an event description from the 2002-2003 and 2003-2004 Houston contests are given below.

Teacher training and networking are significant components to the program. A series of committee meetings are held around the city of Houston during the summer and fall that have three objectives, inform teachers about the program, give interested teachers the opportunity to network, and to give teachers an opportunity to make inputs into the rules. A workshop to prepare teachers who are considering entering their students in the Mars Rover Competition is held each year in early Fall at the University of Houston. If the schedule works, we team-teach the

workshop, with a science professor, a curriculum professor, and an experienced senior teacher joining forces to present the material. We also try to have a couple of past participants there to act as demonstration students. The workshop goes into considerable detail regarding the elements of the curriculum, what works and what doesn't. The presentation also covered where the teachers can get resource materials to use.

All of the curriculum materials, national and community resource materials, contest rules, etc. are made available in multiple formats if possible via a contest Web Page located at http://troll.phys.uh.edu/MarsRover/ .

Figure 2. Attendees at the 2002 teacher workshop.

III. Curriculum Elements

A. Mars Unit Overview

The Internet has made modern planetary science instantly accessible to virtually everyone. The process of building a model should be the last step in a much more extensive process of scholarly investigation. The project is one where the students should be taught basic scholarly research skills. Students who have not yet had the opportunity to pursue a research project will learn how to use tools such as the library and the Internet to get the information they will need to complete their project. In the case of the Mars Rover project, students will need to learn some basics about the characteristics of Mars, about the current hot topics in Mars research, about the design of Mars rover robots, about how spacecraft investigate planets, about how to power and ruggedize remote sensor platforms, and a host of other questions. Along the way, we hope that they will discover how exciting it is to solve real world puzzles likes this for themselves.

B. Research the Characteristics of Mars

The students must understand the characteristics of Mars in order to design a meaningful mission. To do this they must learn about the features and conditions on Mars. Library and Internet research skills can be taught or improved by having the students gather information critical for a Mars space probe. The students will use various sources –Internet, NASA materials, videos, CD-ROMS, etc. to find the information they need. The teacher can organize sharing information in a fun way – have student groups teach the class.

C. Investigate the features of NASA's probes

In the course of their research, the students should learn how space probes communicate and conduct experiments on Mars. The teacher should encourage the students to see how space probes are designed to survive in harsh conditions, such as those shown in Figure 3. Teams should learn how rovers are designed and tested. Research of this scope should be a team process. Teachers should encourage the students to share facts and findings. As students review the various past and future missions to Mars, they should note mission similarities. In the Houston area, classes often take a field trip to NASA's Space Center Houston. Schools that are not located near NASA Center can and should invite guest speakers to talk to the class about Mars, space probes or robotics. Schools anywhere can set up facilities for students to ask questions online with NASA experts.

D. Power for Probes

1. Solar Racer (optional)

Powering probes with a solar racer kit is great for learning about solar power and experimenting with various kinds of propulsion. Cost is about $10 per kit. Teams of about 2-3 are practical. Teachers will find in necessary to

Figure 3. Mars Rover 2004 event poster. The poster was a collage of pictures taken the week before the event by Spirit .

approach taken by the teacher. The requirement that the students must choose their own Mars mission and must select their own instrumentation suite to accomplish that mission gives the teacher the opportunity to assign a very substantial research paper without anyone noticing or getting freaked out at the prospect. The students' research should begin with a review of the surface conditions on Mars. They should also be encouraged to use the Internet to review highlights of NASA's probes to Mars. In class, the teacher should review the judging criteria for the 2004-5 Rover Competition (Figure 4). Early in the program, the teacher should arrange to form Rover Design Teams of 3-4 members. As a starting place, the teams may begin by completing the leading questions in the Mars Rover Guide.

They should review the list of suggested missions and possibly select one from this list. Imaginative and accomplished students should be encouraged to develop their own mission concept. The team should obtain consensus on 2-3 objectives for their mission. The teacher is encouraged to help the students examine a map of Mars to locate an appropriate landing site that will permit accomplishment of the mission goals.

Design of the probe or rover is the final step. The team will need to brainstorm the technology and features needed to accomplish

provide some formal instruction on pieces in the kit, the assembly options, steps and pitfalls. It is particularly important for the teacher to emphasize safety using the tools – such as knives and glue guns. It is helpful to the students for the teacher to show a finished sample of each type of propulsion. We have found that this project runs best if there are lots of parent helpers to help solder and to assist teams. Parents should be cautioned that they are there to be solder techs, not to do the projects for the children.

2. RC Car (optional)

Powering probes with an RC car kit is great for learning about remote control and having a model that does neat stuff. In Houston this year eligible kits include Kelvin Model 280511 and Radio Shack Model 60-4394, both of which retail for about $25. The Kelvin kit is pedagogically superior in that it requires more construction to complete.

E. Design Teams Decide on Mission, Rover Features & Create Initial Draft with the Criteria in Mind

This project can be given very substantial academic depth, depending on the organizational


The 2004-2005 Mars Rover Model Competition

Judge's Evaluation

NAME OF ROVER_____

SCHOOL or ORGANIZATION_____

☐ Solar Power Kit ☐ Free-Form ☐ RC ☐ Primary (3-5) ☐ Middle (6-8)

<--AVERAGE--❶❷❸❹❺--EXCEPTIONAL-->

Mission goals clear, well understood, worth doing (20 pts) ①②③④⑤
valid science objective – appropriate site selection – knowledge of Mars – investigation strategy

Creative, clever rover concept suitable for mission (10 pts) ①②③④⑤
tools to fit the job – innovative science feature design – knowledge and application of space technologies

Sound plan to operate rover and return science data (10) ①②③④⑤
remote control vs. automation – measurements to take – communication lag time

Well adapted to the harsh Martian conditions (10 pts) ①②③④⑤
enough power for the job – survive the brutal Mars weather– rover abilities suitable for terrain of selected site

Well-built model for low cost (20 pts) ①②③④⑤
cost limit not exceeded – resourceful use of existing materials – constructed with care – looks good

Rover Guide booklet complete, well written (10 pts) ①②③④⑤
booklet complete – well organized – reflects knowledge of Mars, mission, and model

Team effort (10 pts) ①②③④⑤
balanced assignments – camaraderie – cooperative creation – clearly documented

Organized, well performed group presentation (10 pts) ①②③④⑤
informative – creative – consistent with documentation – well prepared – coherent - entertaining
articulate – could answer questions

Overall ranking of this team among teams I scored: ①②③④⑤⑥⑦

NAME OF JUDGE_____

Draft Version: 9/8/2004 Subject to Revision until 11/20/2004

Figure 4. 2005 Judges' Evaluation Sheet

their mission. They will also need to brainstorm features to handle the harsh conditions – cold, dust, and rough terrain. The students should be given some insights into the design process. Encourage them to plan before beginning to build. Strongly suggest that they sketch an initial design incorporating the team's ideas.

F. Build rovers using craft materials

For many of the kids, building the rover is the most fun (see Figure 5). The teacher needs to exercise care to keep the assertive alpha student from dominating a group. Make sure that the kids emphasize teamwork and group decision making in the process of constructing the model. The teams should use various arts & craft supplies along with materials available from the store – foil, cups, Styrofoam trays, straws, spoons, etc. Use book tape and hot glue for assembly of the pieces.

Figure 5. Two 8th grade students building a demonstration model during a teacher training workshop.

G. Plan Presentation to Share their Team's Mars Rover

Figure 6. Lights, camera ... skit!

One of the requirements for the contest is the presentation of a 5 minute skit (Figure 6). This skit also makes a useful vehicle for the teacher's formal evaluation of the work. Presentation day is a student favorite in the elementary schools that use this program as a formal unit.

The teacher needs to explain the criteria for the presentations. Use of a rubric sheet or checklist for presentation development is often useful. Teachers should encourage creativity with skits, props and costumes. The skits should be somewhat fact oriented. The objective of the skit should be to explain the mission. It should identify key features and highlight the rover's capabilities in the extreme conditions.

The teams should not be allowed to "wing" their skits. Teachers should require composition of a written skit script. The teams should be strongly encouraged to practice and rehearse their skits.

H. Enter & win the competition!

The city-wide contest that concludes the program is a fun and challenging part of the program that provides motivation, additional learning opportunities, and, for many, a first exposure to a University. It is up to the teacher to submit an entry, organize transportation, and engage enough parents in coming along to ensure adequate supervision. The kids need to show up with their models and documentation complete and in top shape. They will have an opportunity to show their models too NASA engineers and to get professional feedback on their ideas (Figure 7). They need to wear their costumes and their brightest smiles (Try to stop them! See Figures 6, 8 and 9). Above all else, they should focus on having fun in what they are doing.

IV. Project Rationale

The Mars Rover project offers distinct educational possibilities for middle level science educators. The prevalent climate in today's school is dominated by tests, accountability, and academic achievement defined by correct knowledge responses on paper-pencil tests. Informed science educators recognize that is a narrow view, one

Figure 7. Judging in progress during the 2004 event.

devoid of important psychological components. Student affect towards science and their perceptions of the school science relevance are important considerations. This is particularly significant if the educational community is to sustain or enhance the career pipeline for science-related higher education.

The Mars Rover project offers rich opportunities for upper elementary and middle level students to develop not only cognitive outcomes associated with state mandates but also critical affective characteristics. These affective dimensions include positive attitudes about science, positive perceptions about the relevance of science, knowledge ownership, and situational empowerment. Projects such as Mars Rover provide a context in which students authentically engage in a goal-oriented, long-term task that requires multi-faceted efforts. In short, the students must invest both emotionally and cognitively in a self-regulatory manner in many activities in which they have control. Further, they produce a physical product that they display, communicate, and value. Knowledge ownership (This knowledge is important to me.) results because students plan, create, invest, prize, and publicly affirm their educational products in a self-regulatory mode (see Figure 9). Situational empowerment (I can do science.) because students develop a sense of efficacy in terms of their abilities to achieve, complete, and be successful in a scientific context. Mars Rover is win-win in terms of both cognitive and affective outcomes.

The science education opportunities of projects such as Mars Rover are critically important for students from social and economic backgrounds devoid of a scientific dimension. Parental profession is a key predictor of future career choice in many career tracks. School sciences alone, with its current memorize and test emphasis, will not win the hearts and minds of students. Mars Rover provides a needed context for students to undertake and benefit from a more authentic science-related experience.

Figure 8. Bright smiles, bright kids, and a very bright future.

V. Mars Rover Program as a Teaching Unit

The Science Magnet Program is a Clear Creek ISD District-wide program offered to students in grades 6-8. It is housed at Seabrook Intermediate School and provides a unique science curriculum for all students in the school while providing additional science electives and opportunities for students enrolled in the Science Magnet Program.

Traditional science classes are replaced with an unparalleled selection of one-semester courses and extra events that encourage multidisciplinary approach to instruction. Explore Some More Teams are formed by students who volunteer to learn more about a particular program or project for a given period of time outside of the school day. The Explore Some More programs offer families a chance to become involved with the activities and experience of their Science Magnet student. The Mars Rover Project is one of these Teams.

Figure 9. 2004 contestants presenting their work. Their enthusiasm and engagement is evident.

Through participation in the Mars Rover Project students become engaged in a fun and exciting educational engineering program that combines a stimulating engineering challenge with a "hands-on" application to design and build a rover model that could function on the surface of Mars. Students must pick a task for the rover to accomplish and explain how this task would be done.

The Mars Rover Project is designed to be a six weeks, classroom lesson. However, since this Science Magnet Program does not afford classroom time, it has been modified to be accomplished after school on students' own time. Much must be learned before the actual building of the rover can happen. Not only must students learn about the planet Mars, but they must understand what it takes to design a vehicle to explore its surface, learn of its history, and bring that learning back to Earth. Students must learn to work as a team, communicate, find information on the web, in books and periodicals, and from engineers and scientists in the field. As this school is located less than 5 miles from NASA/Johnson Space Center, and many of our parents work on the Mars Project, there is a marvelous opportunity for students to have a career connection with employees who can explain not only what they do, but what education it took them to accomplish their dream.

Students must pick a sub-team for research of the planet, planning a skit about Mars and the rovers, designing different parts of the rover, and the actual building of the rover. Rovers can be static displays, solar powered, or battery powered and all enter into a different group for the actual contest.

But, for us, the winning of a contest is not the prize. The prize is the learning, the teamwork, the job skills, the friendships, and the ability to create and be creative.

A. Standards Based Objectives

The nation has Educational Standards that must be met and Science Standards are just one of them[1]. Most states have state standards that are aligned with the National Standards[2,3]. In Texas those standards are called TEKS (Texas Essential Knowledge and Skills). Teachers are required to cover certain standards throughout the year in each class.

The Mars Rover Project allows for certain Standards to be addressed and fulfilled. All lessons should contain a reference to the Nature and History of Science, Science and Mathematics, and Science and Technology. Students should have laboratory and field experiences, be able to investigate, collect data, infer, engage in hands-on activities, and communicate to others lessons learned. They must also practice all the Science Process Skills and defend their findings in writing. The Mars Rover Project fulfills these requirements.

The students of the Science Magnet Program are in the third year of competition. They have taken home first place, second place, third place, fourth place, and fifth place trophies for different categories through these years. They have also taken home a greater understanding of the world around them, the skills needed to exist in this world, and a view and vision for the future through space travel.

VI. The City Wide Competitions

Figure 10. "Yes sir. I know that real spacecraft use white duct tape..."

The University of Houston has undertaken to foster and nourish the use of Martian surface probe studies as an enrichment vehicle for Grades 3-8 in the greater Houston area, comprising Harris County and the entirety of all 8 contiguous counties. The University regards this program as one element of many is in a broader effort aimed at community outreach and, ultimately, client development. The opportunity to compete with other schools around the area, and to learn from what these other students and teachers are doing is one that adds both excitement and depth to the Mars Rover program. Organizing the competition has entailed several steps, including publicizing the event, developing a teacher training program, establishing a budget, raising funds, arranging other sponsorship, locating a venue, buying trophies and signage, ordering food, recruiting the ~100 volunteers needed on event day and managing the event on the big day.

A. Publicity

Publicity for an event such as this has three components: informing teachers of the opportunity to participate, informing the public of the event, and publicizing the winners. The first step is by far the hardest. We use four components. The University issues a press release, we send an email to all prior participants, we send an e-mail to all local district superintendents and science curriculum coordinators, and we ask the county department of education to email all elementary and middle school principals. The second step is the only really effective one. Ideally, we would have a work-study student transcribing the email addresses of every elementary and middle school science teacher in the 8-county area from all the relevant school web pages. Unfortunately, we have not had the budget for this effort. Publicizing the event is done through University media relations and local news coverage. The first year, the winners were displayed at World Space Congress. This year, we will arrange display at the Houston Museum of Natural Science. If time and money permit, we produce a poster (Figure 3).

B. Teacher Training

The teacher is the key to the success of this program. It is very important to be sure that teachers who are new to the program get a complete introduction to all aspects of the program as early as possible in the school year. We try to accomplish this by running a teacher training work shop on a Saturday morning in early September (Figure 2). The workshop is taught be an experienced teacher, a science professor and an education professor. We allow 3 hours to cover the material. We cover all aspects of organizing and teaching the Mars Rover program. We try to emphasize the formal curriculum connections and methods for teaching science in the context of the program. If we have been able to recruit some 8th grade demonstrators, we have the kids build a rudimentary model during the workshop (Figure 5). We also try to give the teachers access to as many Mars education resources as we can. The cognitive development basis for the program is also covered.

C. Budget and Sponsorship

The budget for the event is shown in Table 1. This budget is somewhat bare-bones, in that snacks during the event are sold, not provided, a lot of the effort is donated by various groups within the University, and we have not included such extras as posters or t-shirts for the participants. At present

Item	Cost
Food	$3,200
Trophies	1,800
Room	800
Set-up	400
Signage	200
Contingency	600
Total	$7,000

Table 1. Budget of 2004-2005 Houston Mars Rover Model Competition

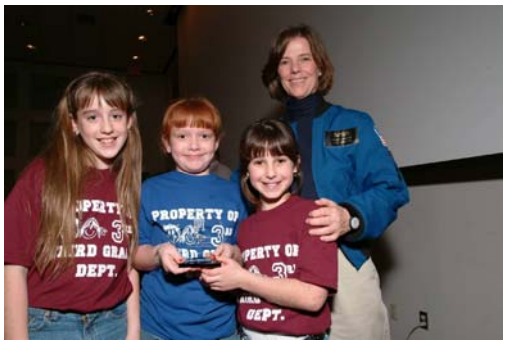

Figure 11. Astronaut Bonnie Dunbar presented the awards at the 2004 event.

our sponsors are a number of colleges and Departments within the University, including the Provosts' Office, the Colleges of Education, Engineering, Natural Sciences and Mathematics, Optometry, and Technology. Departments and Institutes include the Texas Center for the Study of Advanced Materials, TLCC, Physics, and Geosciences. Additional support is provided by the UH student chapter of the AIAA and the Houston Section of the AIAA.

D. Facilities

We have found that 3 rooms are required. First one needs a large hall (350-900 m^2) for display and judging of the models (Figure 7). Second, a nearby auditorium for projection of space movies and giving awards is desirable. Third, you need one or more breakout rooms for the judges to work in. The big hall should be set up with half as many folding tables as there are models entered, plus another 10-15 for food service and registration. It will not be possible to provide chairs for all. Some chairs (~100) for attending adults can be very useful.

E. Materials and Supplies

The required materials include lunch for the judges, snacks during the event, post-event reception, trophies (5 per age group/category=30) (Figures 11 and 12). A 3 hour supply of space related educational videos are also needed. It is nice if sponsoring departments and colleges have booths with hand outs. We have the student chapter of the AIAA act as hosts. They raise funds for their other activities by selling snacks during the judging portion of the event. Have plenty of pencils, paper etc. on hand. Good signage is essential (Figure 3). We have lots of foam board signs stuck in the ground pointing to the event that we put around campus at major intersections. We have big banners for the event itself, with recent Mars photos and so forth. Speakers and a microphone complete your set up.

We also try to have some swag for the participants. Brochures on the University and some nice glossy photos of Mars are the minimum. If we have sponsorship, we also will have posters and t-shirts.

F. Personnel

During the event, there are 5 different major tasks that need to be done. First, the arriving teams need to be signed in, which takes about 6 people. Second, food service will take 3-4 folks. Third, you need to have some senior floaters, to deal with contingencies and some singleton folks such as a projectionist. Fourth, you will need judges. Figure on about 2/3rds as many judges as models (100 in our case). This ratio will enable you to have 6 folks visit each model and complete the judging in 3 hours. Fifth, you will need people to give campus tours.

Figure 12. Third grade rules!

G. Event Management

We try to be as thoroughly organized as possible. There is a stuffed envelope for each teacher, with a schedule, general update, table assignments for each model, and printed certificates for each participant. Mail merge is a wonderful tool! There are labels on each table giving school, model name, model type, and grade level. The judges each get a schedule sheet directing them as to which tables they have to judge and when. Each school also has a pre-scheduled tour time. We mail nice certificates of appreciation to each judge as soon after the event as possible.

VII. Conclusion

This paper has presented a combined curriculum unit and regional competition designed to help provide some excitement and relevance to engineering education in elementary and middle school. The children are challenged to solve the problem of developing a mobile robot or "Rover" to explore the surface of Mars. There are two elements in the concept, a curriculum unit and a contest. The curriculum unit is structured as a 6-week planetary science unit

for elementary school (grades 3-5). It can also be used as a curriculum unit, enrichment program or extracurricular activity in grades 6-8 by increasing the expected level of scientific sophistication in the mission design. The second component is a citywide competition to select the most outstanding models that is held annually at a local college or University. The details of how to teach the curriculum and how to run the contest have been developed in some detail.

Acknowledgments

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