AC 2008-893: DEVELOPING YOUNG ENGINEERS – FROM START TO FINISH

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Larry Lim, the Director of Pre-College Programs at the University of Southern California's Viterbi School of Engineering, has been at USC since 1979. The two most significant programs Lim runs are MESA (Mathematics, Engineering, Science Achievement) and Mission Science. Both programs' main mission is to excite young students about science and engineering. Lim also served as director of USC's Minority Engineering Program from 1989-1996. In a related project funded by Hewlett Packard, Lim also worked with all the elementary schools in the USC neighborhood to improve science education using hands-on, "Inquiry-Based" curricula and materials. Lim also coordinates FIRST Robotics, JETS-TEAMS, and teacher professional development programs for k-12 teachers.

Lim has also worked for thirteen years as a physics, chemistry, and mathematics teacher at Belmont and Venice High Schools in the Los Angeles Unified School District.

Developing Young Engineers – From Start to Finish

Abstract

Creating and maintaining an interest in engineering requires a multi-year, multi-faceted effort that begins in elementary school. The University of Southern California Viterbi School of Engineering offers a continuum of k-12 programs that provides a pipeline into engineering as a college major.

Our efforts begin with a program for elementary school students – *Mission Science*. Located in eight sites in both the University Park (central Los Angeles) and Health Sciences (east Los Angeles) campus neighborhoods, Mission Science provides hands-on workshops, with tools and workbenches so students can develop projects on their own, experiment with equipment and ideas, and learn about science in an informal setting. The fundamental purposes of Mission Science are to reinforce the natural curiosity of children and to help develop enthusiasm about science and technology by providing "hands-on" activities, demonstrations, projects, and experiments. More than 500 students participate annually.

Following Mission Science is our Mathematics, Engineering, Science Achievement (*MESA*) program. MESA identifies students with interest and potential for an engineering career. MESA students meet on a regular basis and participate in a variety of motivational, informational, academic, and competitive activities that prepare them for college and a major in engineering, math, or science. The program exists in twenty-two middle and high schools, serving nearly 1500 students each year, with more than 90% of the seniors enrolling in college upon graduation.

During the summer, we offer *Discover Engineering*, a month-long, residential program to introduce high school students to the various engineering disciplines. In addition to academic work, students participate in field trips to engineering work-sites. Students receive three units of college elective credit for completing the program. In 2008, in addition to *Discover Engineering*, we will also offer a two-week, commuter program, *Mission Engineering*, specifically targeting educationally disadvantaged students.

To promote student competitiveness, the Viterbi School of Engineering is also a host site for two national competitions: JETS-TEAMS and FIRST Robotics. These competitions give students the “hands-on” experience of engineering, and the excitement of participating in a technical competition.

Our Pre-College program office also offers professional development to teachers to aid them to sharpen their skills and increase their understanding of science and engineering. This is done via a two-week, summer Math, Physics, Technology Institute. MPTI brings together math and science teachers from both high schools and middle schools, and provides them with math and physics curriculum and lessons, using Texas Instruments technology, that they can then incorporate into the curriculum at their respective high schools.

Creating a pipeline for future engineers requires creative ideas, resources, and educational activities that promote the field to students of all ages. Developing a model that can address the needs of students at various levels of the educational spectrum is key to the success of this effort.

Pre-College Programs Overview

In 1977, the USC Viterbi School of Engineering implemented it's first pre-college outreach program to increase the number of young students entering college with engineering as their major. With funding through the University of California, we implemented the MESA (Mathematics, Engineering, Science Achievement) program initially in three high schools in inner-city Los Angeles: Fremont High School, Jefferson High School, and Manual Arts High School. In 1977, all of these schools had predominantly African American student populations. Belmont High School, which had a predominantly Hispanic student population, was added to the program the following year. Our MESA program worked with some 400 students at these four schools at that time.

Although MESA was quite successful, it became evident that working with students in high school by the high school years was too late; by then many students had already opted out. In 1983, we expanded our program to include feeder middle schools. Working with middle schools provides the opportunity to work with students for as many as seven years. Subsequent expansions brought us to our current size of twenty-two middle and high schools, working with more than 1200 students each year.

MESA provides a blend of activities that both motivates and prepares students for college engineering courses. With our strong relationships with industry, working engineers from companies including Unocal, Pac Bell, Bechtel, McDonnell Douglas, the Aerospace Corporation, Northrop Grumman, TRW, IBM, Hewlett Packard, as well as university engineering students, visit our schools and speak to students about their careers, work environment, salaries, as well as what they did to prepare themselves.

At each school, one or more teachers (usually math or science) serve as the direct contact with students. These teachers assist in building leadership skills, develop a sense of community – including parents and other community members – and ensure that students are well prepared for college and engineering. They recruit students into MESA, serve as liaison with the university, hold meetings with MESA students on at least a weekly basis, coordinate activities, complete required paperwork, review each student's individual academic plan, and monitor student progress. Typically, teachers receive a modest stipend for their efforts. The university provides curriculum, activities, teacher training, materials and supplies, and program evaluation.

The MESA programs at the schools are in two formats: weekly lunch or after-school meetings, or daily MESA periods. The format at each school is determined by the school's principal, and depends on the individual school's needs and constraints. During these meetings, students participate in MESA core components. Core components include: academic support – Academic Excellence Workshops/tutoring, study skills development, college admission exam (SAT/ACT) preparation; college and career exploration – field trips, speakers, College Day and college visits; counseling support – Individual Academic Plans, college advisement and help with admission and financial aid applications; hands-on science and engineering activities and competitions; student leadership development; and parent involvement.

Each semester, field trips to an engineering company (e.g. JPL, Northrop Grumman, Chevron) or science site (e.g. USC Wrigley Marine Science Institute on Catalina Island, California Science Center) are organized for the schools. Field trips to engineering companies show students the engineer's working environment and give them the opportunity to talk with working engineers about their profession and careers. Tour guides are generally young engineers who relate well with pre-college age students. This vision of the future is vital. Field trips also give the hosting companies the opportunity to showcase their organization to potential future employees.

College Day is the major college information event of the fall. In the morning, we offer a series of two dozen workshops, including: How to Choose a College, How to Choose a Major, College Costs and Financial Aid, The SAT and ACT, College Student Life, What Engineers Actually Do All Day, etc. Following the workshops is a College Fair with approximately fifty colleges and universities represented. More than 1500 high school students participate each year.

Competitions are a key component to our program. In addition to the learning that accompanies competitions, they give students the opportunity to compete and test themselves against their peers at other schools. Except in athletics, students have little opportunity to experience competition. This is particularly true at inner-city schools, often leading to the students having a limited perspective of their skills and abilities, and they may enter college with an inflated view of how they compare with other students.

MESA Day competitions are the focus of the spring. Goals include:

- Provide students with an opportunity to apply mathematics, science and engineering principles to individual and team academic contests
- Expose students to college campuses, college faculty, technical equipment and laboratories
- Build self-esteem and confidence in students
- Encourage and motivate students to excel
- Recognize student academic achievement

MESA Day competitions include: Mathematics, Trebuchet, Mousetrap powered car, Egg Drop, Model Bridge Building, Soils Science, Web-page design, Crystal Growing, Speech, Balsawood Glider.

We also host or are affiliated with national engineering competitions for all schools and students, including JETS-TEAMS and FIRST Robotics.

JETS (Junior Engineering Technical Society) offers the TEAMS (Test of Engineering Aptitude, Mathematics, and Science) Competition each year. This unique and challenging national paper and pencil competition for high school students helps them learn how math and science concepts learned in school are applied to real-world problems. The competition introduces students to an "engineering team" work environment where students work cooperatively in an open-book, open

discussion environment to solve objective and subjective engineering problems. Students submit a single answer sheet for their team. JETS TEAMS gives schools the opportunity to compete against schools of similar size, and for urban schools to compete against suburban schools.

The FIRST (For Inspiration and Recognition of Science and Technology) Robotics Competition immerses high school students in engineering. Teaming up with engineers from industry and the universities, students get a hands-on inside look at the engineering profession. In six intense weeks in January and February, students and engineers work together to brainstorm, design, construct, and test their robot built from scratch from an initially common set of motors, pneumatics, and electronics. The local Regional Competition is usually held in March at the Los Angeles Memorial Sports Arena where nearly 60 robots “battle.”

Recognition of achievement is also important. At the close of each year, we host a year-end banquet where student achievement is recognized. Graduating seniors also step forward to announce the college they will enroll in and major they will pursue. This serves as strong motivation for younger students and their parents and family members.

Elementary school students typically spend less than one hour of class-time a week on science, so beginning to work with middle school students is also too late. Work must begin at the elementary school level. The Viterbi School of Engineering offers *Mission Science*, a program for community children and their families initially funded by the National Science Foundation, now funded primarily by USC Neighborhood Outreach grants. The fundamental purposes of Mission Science are to reinforce children's natural curiosity and to instill an excitement about science and technology by providing "hands-on" exhibits, demonstrations, projects, and experiments. Mission Science provides a real workshop, with tools and workbenches so students can work on projects on their own, tinker with things and ideas, and learn about science in an informal atmosphere.

Mission Science began operation here in August 1996 with after-school and evening programs. At Mission Science students find exhibits demonstrating science concepts. These exhibits are patterned after San Francisco's Exploratorium. Our exhibits differ from museum's exhibits in that ours are "home-made" by us out of common, everyday materials and recycled equipment. The young students are encouraged to play with the equipment, observe the results, and discover the underlying concepts. Since the exhibits are homemade from common materials, they are easily repairable, and students won't have to be concerned about breaking them.

In addition to the construction projects, students also have the opportunity to take things apart. Old telephones, radios, typewriters, and other similar devices were collected for dismantling. This activity not only allows students to take machines apart themselves, it allows students to see what things are made of and how they work.

Student projects include making: ice cream; a motor from a paper cup, magnets, and wire; “floating” pencil; rockets with various forms of propulsion (baking soda/vinegar, compressed air, water bottle); speedboat; kaleidoscope; cotton candy machine; helicopter; electronic true/false; soda can model car; and more.

Mission Science also has an impact on the entire family. While some parents simply observe their children practicing science, many actually join in with the children and staff and learn about science and technology themselves. Many Mission Science students take home their projects to show and teach their younger siblings.

These after-school Mission Science programs are located in seven elementary schools and at a Boys and Girls Club. All of the sites are located in south-central Los Angeles and in east Los Angeles. All Mission Science sites are open to children on a drop-in basis, free of charge. Nearly 750 young children participate in Mission Science each year.

Summer Programs

While our primary interaction with students occurs during the traditional academic year, the summer gives us the opportunity to work with students in a more intensive and focused program.

We offer two summer programs. *Discover Engineering* is our four-week, residential summer program. It provides academic lectures and discussions that cover many engineering disciplines including Aerospace, Biomedical, Chemical, Civil, Computer Science, Environmental, Industrial & Systems, and Mechanical Engineering. Students experience engineering through industry field trips and the development of problem solving techniques. Students gain engineering experience by working on team-oriented, hands on assignments as they design, build, and test their own projects. We also offer *Mission Engineering*, a two-week commuter program with similar curriculum specifically targeting disadvantaged students.

Summer Syllabus Sample Projects

Engineering Challenge: Minimize human radiation exposure during lunar research station site construction:

Engineering Disciplines:

- Electrical Engineering – Radiation sensor and alarm
- Computer Science – Robot programming
- Mechanical Engineering – Robot design structure

Proof of Design:

- Design and build a circuit that given a certain level of radiation will raise the alert level
    - Acceptable levels – Green light
    - Elevated levels – Yellow light
    - Hazardous levels – Red light, sound Alarm
    - Deadly levels – Seal off area
- Design robot that
    - Autonomously gathers and retrieves soil samples for analysis
    - Autonomously clears obstacles
    - Levels a graded surface with user input

Other commercial applications:

- Minimize risks to military contractors during post-war reconstruction activities.

Engineering Challenge: Water monitoring

Engineering Disciplines:

- Chemical Engineering – Real time water quality monitoring
- Industrial Systems Engineer – Collection, monitoring and distribution system

Proof of Design:

- Design water monitoring system that
    - Monitors water quality as it's being delivered in real time
    - Transports acceptable water to distribution point and redirects contaminated water to collection point

Other commercial applications:

- Water monitoring in pollution prone areas

Engineering Challenge: Safe transport of personnel through space

Engineering Disciplines:

- Aerospace Engineering – Rocket design
- Biomedical Engineering – Passenger compartment
- Civil Engineering – Launch tower structure, theodolite

Proof of Design:

- Design, build and launch a model rocket, launch tower and a device for measuring altitude. The rocket must be capable of carrying a payload (an uncooked egg) 200 ft and returning it to earth undamaged

Other commercial applications:

- Improve passenger safety systems could be used to minimize injury and fatalities due to airplane crashes

Teacher Professional Development

Another component of our program is teacher professional development. In inner-city schools, a significant percent of teachers who teach math and science have limited math and science backgrounds. Most mathematics teachers have at one time or another been faced with the question from students: "What do I need this stuff for?" School mathematics is taught typically in the abstract. It is difficult to answer such a question when concepts are taught in isolation from the contexts that give them meaning.

An understanding of how mathematics fits into real world contexts by connecting the data from science class with the functions studied in mathematics class helps both teachers and students anchor mathematical abstractions to reality.

Science teachers face a different challenge. Students usually understand the real world relevance of what they are being taught in the science class, but science teachers are dependent upon the mathematical content knowledge of their students. If the math knowledge is insufficient, typically, science teachers have to modify instructional goals by simplifying the science or supplying the mathematical procedures without explanation.

In order to create an environment in which mathematics and science are *not* taught in isolation, we offer a professional development experience for teams of mathematics and science teachers. Using technology as a tool, science teachers develop a greater understanding of how to reinforce the learning of mathematical concepts and mathematics teachers learn about real world application of mathematical concepts. Mathematics-science teacher teams familiarize themselves with common vocabulary and opportunities for mathematics and science teachers to converse about content and pedagogy.

The main activity of the professional development program is a two-week summer Mathematics, Physics, Technology Institute. The content of the summer MPTI is based upon rigorous, high level mathematics and science (physics) content and is aligned to the California Academic Content Standards. Technology is used in experiments commonly done in middle school and high school, with electronic data collection and calculator analysis of the data using Texas Instruments graphing calculators and sensors. Upon completion of the summer institute, teacher participants take part in a series of five academic year Saturday follow-ups that include additional content presentations, discussions of student work, and the administration of student assessments.

For elementary school teachers, we offer a professional development series in collaboration with the NASA Jet Propulsion Laboratory and the university's earth sciences and marine sciences departments. As mentioned earlier, elementary schools typically devote less than an hour per week on science, with most of that time spent just reading about science. Additionally, the typical elementary school teacher often has extremely limited science background, and may also be science phobic. Our professional development series focuses on training teachers to use hands-on activities based on the Mission Science activities. By actually doing the activities as students, the teachers gain insights into both the science concepts as well as student pitfalls. This series is offered over two days each semester.

Industry Support

Support from engineering industry has been vital to our program. Our Industry Advisory Board, comprised of representatives from approximately a dozen engineering companies, meets quarterly, provides us resources, guidance and current market trends. In addition to financial support, companies provide volunteers, field trips, speakers, and mentor and role models for young students, and event and competition volunteers and judges.

Conclusion – Lessons Learned – Next Steps

The results of our program are quite strong. Each year, we now graduate more than 175 high school seniors from our MESA program. Over the last five years, on average, more than 93% have enrolled in college, with more than 80% of those enrolled in a four-year college or university, and 60% of those majoring in a science, engineering, or other math-based discipline.

In addition to academic preparation and college and career information, MESA has provided students with a cohort of peers, with a culture motivated to attend college. This college-going community, typically missing among other inner-city school students, made the critical difference. Students need the positive influence and support of their friends with similar goals.

Keeping students as active participants in a program over many years is challenging. Students often lose interest if they see only the same things year after year, particularly over the transition from middle school to high school. As a result, our program is organized around a series of activities with increasing complexity. For example, students begin robotics activities using LEGO Mindstorm kits, then move up to VEX, and ultimately to the 120 pound FIRST robots. Another example is model bridge competition, where students start with paper file folders as the material for their first models, then Popsicle sticks, and lastly balsawood.

Coordinating programs and services with other university programs has also become increasingly important. The University of Southern California offers arguably the largest number of outreach programs of any university. This can present challenges in scheduling facilities, competing for students (pre-college and university student volunteers), and duplicating services. We are addressing this issue by formally collaborating with the other major USC outreach programs. The directors of each program meet on a monthly basis to coordinate efforts and to plan mutual activities.

An area we will be expanding in the coming months will be our work with students' parents. Many parents of inner-city students are of limited education and can offer minimal educational help to their children. Encouragement is about the best many can offer. We've come to realize that this significantly limits children's learning. By increasing parents' knowledge of science and engineering, and their understanding of its importance, we will increase the chance of student success. In partnership with a local non-profit organization, we will be offering a series of "Family-Science" workshops at elementary schools during the evenings. Parents and their children will come to a series of five or more evenings each semester and participate in hands-on science and engineering activities around concepts such as aerodynamics, light and color, electricity and magnetism, and forces and motion.