Attracting Under-Represented Groups to Engineering and Computer Science

Dr. Claire McCullough

Abstract

As the demand for engineers, computer scientists, and other technically trained professionals grows in our increasingly technological society, the problem of attracting and retaining members of under-represented groups to these fields is becoming increasingly more critical. To address this issue, many universities, schools, and organizations have put in place programs to encourage under-represented groups to pursue technical careers. This paper presents an overview of the many different programs and approaches being directed toward this goal, concentrating on those currently being funded through the National Science Foundation’s Gender Equity Program. While the Gender Equity Program funds primarily activities aimed at increasing representation of women in the fields of Science, Mathematics, Engineering, and Technology (SMET), it does also support programs which address the under-representation of males, from such groups as the economically disadvantaged, Native Americans, African Americans, and Hispanics, in these fields. These Gender Equity programs currently include school-based programs at all age levels from elementary school through graduate study; teacher education programs; informal education programs, including summer programs, after-school programs, and museum-based programs; software and website development; and conference and publication related activities. A representative selection of programs is described in detail. A special discussion is given on the University of Tennessee at Chattanooga’s Adventures in Computers, Engineering, and Space (ACES) program to encourage middle school girls to consider careers in these fields, and to continue their education in science and mathematics. Each of the programs discussed can serve as a model for other communities concerned with under-representation of women, ethnic groups, and socioeconomic sectors in technical careers.

The Problem of Under-Representation

“Under-representation” is defined in the literature as a group having a percentage representation in a given field significantly inconsistent with its percentage occurrence in the population. That women and minorities such as Hispanics, Blacks, and Native Americans continue to be under-represented in the fields of engineering and computer science can be clearly seen by an examination of the population demographics and degree breakdowns by race and gender in Women, Minorities, and Persons with Disabilities in Science and Engineering (National Science Foundation, 2000). Women in 1997 comprised 51% of the general population of citizens and permanent residents in the United States, and, as illustrated in Figure 1, 49.3% of the population in the age range 20-29. Statistics show the percentage of bachelor’s degrees awarded to women of those awarded in 1996 to citizens and permanent residents was 55.2%, and degrees in “Sciences and Engineering” at 47.1%. However, the government’s definition of “Sciences” includes such areas as Sociology, Anthropology, Linguistics,

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Ethnic Studies, and Psychology, in which women receive the majority of degrees granted. A closer examination shows that in the same year, women received only 17.9% of the bachelor's degrees granted in engineering fields and 27.6% of those in computer science. (1997 population information and 1996 degree information was used, as this was the most recent, and most time consistent, information available).

An examination of the population and degree statistics for Blacks, Hispanics, and Native Americans from the same source (illustrated in Figure 2) shows even more striking under-representation in all fields. Blacks, who represented 13.6% of the population in the age range 20-29, received 5.1% of the bachelor's degrees in engineering and 10.9% in computer science; Hispanics, at 14.1% of the population, formed 6.4% of engineering, and 5.8% of computer science, degrees; Native Americans, .8% of the population, received .4% of both engineering and computer science bachelor's degrees. The only group that had a higher representation in technical fields than their percentage of the population was Asian/Pacific Islanders, who at 4.3% of the population of citizens and permanent residents in the age range 20-29, received 11.7% of the undergraduate engineering degrees and 11% in computer science.

When all sources agree that this nation will become increasingly more dependent on technology in the current century, we must find a way to include these under-represented groups in engineering and computer science careers to meet the future personnel demands in these fields. In
“Underrepresented Minority Achievement and Course Taking—the Kindergarten-Graduate Continuum,” Richard Tapia and Cynthia Lanius of the Center for Excellence and Equity in Education at Rice University, (Tapia and Lanius, 2000) quote a 1999 Computer Technology Industry Association (CompTIA) study estimating a shortage of IT professionals in the U.S. of approximately one million workers by 2001, and then note that under-representation

... has never been a threat to science or mathematics, because when we need more scientists or mathematicians, we import them, and science and mathematics lives on. That's the way we, as a nation, have dealt for decades with SMET shortages...[The United States] imported scientists during World War II; math faculty in the 60's from England (and questionably left England in a bad situation); graduate students since the 70's; and faculty today. Yet now our quick-fix importation strategy fails us. We can't possibly import fast enough to solve our IT shortages. Experts say that if the U.S. imported all the IT workers it needed, this would leave Europe in dire straits. And frankly, what would contribute more to the general economic health of the nation, import more, or prepare domestic workers to fill these jobs?

Programs to Address Under-Representation

The problem of under-representation can have a variety of causes, including problems of access and problems of attitude: personal, familial, and societal. Which factor, or which combination of factors, would prevent an individual from an under-represented group from seeking a career in engineering or computer science depends on the personality and the circumstances of that individual. Thus no one approach, however excellent, can hope to be effective in having significant impact on a problem of this magnitude. In addition, the question of at what point, or points, intervention is most effective does not have a single answer. Programs exist which employ formal education at elementary school, middle school, high school, under-graduate, and graduate institutions. Informal education programs make use of such collaborators as museums, Girl and Boy Scouts, and industry to impact both attitudes and access. Mentoring programs, both in person and virtual, have been used at all levels, from K-12 up through professional practice in technical fields.

Many programs and approaches are being applied in this country and worldwide. While the number of programs makes it impossible to discuss all in this paper, the programs highlighted here illustrate the spectrum of approaches that are currently being tried, and the emphasis which government, industry, and educational establishments place on solving this problem. Programs were chosen for discussion based on factors such as success, level of innovation, population addressed, and variety of approaches. Programs include both those that address engineering and computer science directly, and those that address other relevant areas such as mathematics and physics.

Exploring Physics in Cyberspace

One program that seeks to intervene with under-represented students in grades 5-12, by a variety of methods, is the Promoting Young Women in the Physical Sciences program at the University of Missouri-Columbia. This program is supported by a grant from the National Science Foundation Gender Equity Program (NSF-HRD-96-19140), and is directed by Professor Meera Chandrasekhar of the Department of Physics and Astronomy. The program relies on cooperation among University of Missouri personnel, the Columbia public schools, industry, and parents of the participants to encourage interest and participation in the physical sciences, primarily by young women. The program includes activities designed to influence the students directly, activities aimed at increasing parental awareness and support for their daughters' interest in the physical sciences, and programs to increase both subject knowledge and gender equity awareness of middle school science teachers.
The first portion of the program for the students is Exploring Physics, an after school program for girls in grades 5-7. In this program, girls participate in eight 90-minute sessions, taught by science teachers, and comprised of hands-on activities in areas of physics such as mechanics, electricity and magnetism, optics, and sound. The program is currently available in several Missouri schools, and includes approximately 400 girls each year. Families Exploring Science and Technology (FEST) involves both boys and girls in the sixth and seventh grades, and their parents, once a week for four weeks. This program includes about 60 families per year, and is taught by science and industrial technology teachers, who guide the families in building a working drawbridge. As this portion of the program involves both parents and children, it can aid in altering parental attitudes as to “appropriateness” of careers in the technological fields for both boys and girls. The Saturday Scientist is a series of Saturday morning activities for both boys and girls in the eighth and ninth grades. These sessions focus on hands-on activities and career exploration, and involve strong collaboration with local industries such as the city of Columbia Water and Light Department, the Fire Department, the Columbia Area Career Center, 3M, and KOMU-TV. The Newton Academy is a ten-day residential summer workshop for girls in grades 9-11, and integrates Physics, Chemistry, Math, and Engineering to aid the girls in constructing a working polymer ball factory. The 30 or more girls who participate in this program each year explore such practical issues as economics and patents, as well as the technical areas of polymers, spectrophotometry, system design, electrical systems, gearing, and graphical solution of the problem of generating the optimal mix.

To aid middle school science teachers in both technical knowledge and gender equity considerations, the program includes a course in gender equity, designed for practicing teachers, and a series of three-week summer physics institutes that cover

- Matter, Mechanics and Energy
- Electricity and Magnetism
- Optics and Sound.

As a means of spreading the concepts and influence of the program beyond the Columbia area, the project personnel are currently developing a CD-ROM called Exploring Physics, which will contain hands-on activities from the electricity and magnetism unit aimed at children in grades 5-9. Some of the activities can currently be accessed at the project test site, http://www.exploringphysics.com.

According to Professor Chandrasekhar, the ingredients which have made this program a continuing success included clearly defined themes, hands-on activities, and “take home gadgets” to engage student interest, and involvement of both parents and teachers who deal with the students to influence attitudes and reinforce lessons learned by the children. More information about this program can be obtained from the project website http://www.missouri.edu/~wwwepic/ or from Professor Chandrasekhar at meerac@missouri.edu (Chandrasekhar, 2001).

**SECME RISE**

Unlike Exploring Physics in Cyberspace, which is based at a university, SECME RISE (Raising Interest in Science and Engineering) is a collaboration between the Miami Museum of Science, the Miami-Dade County Public Schools, and SECME, Inc., a non-profit consortium of school systems, universities, and both corporate and government investors, formed with a goal of increasing the number of under-represented, under-served, and differently-abled students pursuing careers in science, mathematics, engineering, and technology. This three-year project was funded by the National Science Foundation Gender Equity Program (NSF-HRD-98-13891). It built on an earlier project at the Miami Museum of Science, Girls RISE, also funded by the NSF, and on the SECME Clubs, at elementary, middle, and high school levels, which provide students with informal opportunities for hands-on engineering and science activities outside normal school hours.
The goal of SECME RISE was to target 52 middle schools serving 80,000 students to enhance access of girls, especially girls of color, to improved education in science, mathematics, engineering, and technology, and to careers related to engineering. Like the program discussed earlier, SECME RISE employs a multi-pronged approach to influence both the students themselves, and attitudes and knowledge of their teachers and families. A Summer Leadership Academy each year included “a combination of team-based engineering design challenges, technology training, field trips, and opportunities to interact with women engineers.” The engineering design projects included such items as basswood bridge building, an “egg drop” activity, and an introduction to robotics using the Lego Robolab materials (a special, educationally oriented, version of the popular Lego Mindstorms products). The sixth and seventh grade girls for the academy were selected by teachers at participating middle schools. The teachers who performed the selection were primarily those who were themselves participating in the series of in-service workshops offered by SECME RISE staff in the areas of hands-on engineering projects, strategies for gender equity, and integration of technology in the curriculum. In order to reinforce the lessons learned in the summer program, in March the girls were invited back to the Museum for an overnight reunion (the RISE ‘N’ Shine! Camp-In), including hands-on science activities such as a science-based scavenger hunt in the Museum’s “Sharks! Fact and Fantasy” exhibit.

Two methods were used to encourage parental participation and awareness of the SECME RISE activities. One was inviting the parents to the closing day events for the Summer Leadership Academy, including presentation of award certificates, exhibition of the web pages which the teams designed describing their summer activities, a “brain-bowl” quiz, and a competition testing the bridges which the girls had built. Also included was a luncheon, and presentation of each girl with a $300 stipend for participation. The second method used to raise parental awareness was the hosting each year of two family “E-Days” at the Museum. The girls, their parents, and the SECME RISE teachers were all invited to half-day sessions, including hands-on designs, female engineers as guest speakers, career planning information, and discussions of how to best encourage the girls’ interest in science, mathematics, and technology.

In addition to the activities to influence girls, their teachers, and their parents, a further goal of SECME RISE was “to contribute to the research base on how socioeconomic status and ethnicity interact with gender to influence mathematics and science learning.” (SECME RISE, 2001). This will aid other researchers in constructing programs to change both attitudes and access for girls and all persons in under-represented groups to careers in engineering and technology.

The SECME RISE personnel have recently begun a new NSF award building on SECME RISE. Information about all of the RISE programs can be obtained from the program website http://www.miamisci.org/rise/index.html, or from Jennifer Santer, Co-Project Director, Miami Museum of Science, at jsanter@miamisci.org. (Santer, 2001).

**Girls in the SYSTEM**

Girls in the SYSTEM (Sustaining Youth in Science, Technology, Engineering, and Mathematics) is a program aimed at girls in grades 3-8 in southern Arizona, placing special emphasis on Mexican American, Native American, and economically underprivileged groups. The program is funded by the National Science Foundation, and is a collaboration between the Ecology and Evolutionary Biology Department, the Materials Science and Engineering Department, the Mathematics Department, the Mining and Geological Engineering Department, and the Southwest Institute for Research on Women of the University of Arizona, with the Sahuaro Girl Scout Council. The foundation of the program is the STEM (Science, Technology, Engineering, and Mathematics) Academies for teachers, both in- and pre-service, and Girl Scout leaders, geared toward providing
them with knowledge of both gender equity issues, and interesting and innovative approaches to science, technology, engineering, and mathematics. The adults trained in the STEM Academies aid in conducting five one-week summer day camps for boys and girls in the Tucson vicinity. This both aids the children who participate in forming positive attitudes toward STEM subjects, and gives the educators an opportunity to “try out” the materials and strategies learned in the STEM Academies. Some of the adults so trained also facilitate six-week sessions incorporating STEM activities into Girl Scout troop meetings. This emphasis on training teachers and other relevant adults, and then aiding them in working with children in STEM makes this program unique among those discussed. Workshops are also available for families of the children who participate the in the program activities, to inform them about science and technology, and to emphasize to them the great significance of the role of parents in preparing their children to succeed academically. Another aspect of this program which is unique to the programs described here is the availability of mini-grants to parents and teachers of the students who participate and to STEM Academy participants for such activities as presentations to community groups, formation of STEM study groups, and hosting of mother-daughter STEM events. Information on this program was obtained from the project website at http://gistem.math.arizona.edu/ (Girls in the SYSTEM, 2001).

**Techbridge**

Techbridge is a technology program designed for girls in middle and high school, primarily in the Oakland, California area, and is funded by National Science Foundation under Grant No. HRD-00-80386. The name “Techbridge” comes from a recognition that this age range represents a critical time in girls’ development. Girls have many important decisions to make in middle school and high school, but don’t always have the support they need. Techbridge supports girls by teaching them technology skills and helping them plan for the next steps to college and careers.

The activities take place as after-school clubs, lunch clubs, and early morning class meetings. Activities include Lego Mindstorms robots, launching hot air balloons, building radios from kits, movie and web page design, and interaction with female professionals in science and engineering. This program also offers teacher and parent programs similar to those discussed in other programs; more information can be obtained at the Techbridge website at http://www.chabotspace.org/visit/programs/techbridge.asp. However, what makes this program unique is participation of students from the California School for the Blind, in Fremont, California. (Kekelis, 2001)

With the guidance of teacher and community liaison Marcia Vickroy, an after-school science club was established at the California School for the Blind as part of Female Involvement in Real Science and Technology (FIRST), the NSF-funded predecessor to Techbridge. During an emphasis on insects and animals, a professor from a local university brought insects such as walkingsticks and hissing cockroaches for the girls to hold and examine. While some were initially reluctant, all of the girls became “tactilely comfortable” with the insects. A study of animals led to the girls adopting creatures including hares, tortoises, and cockatoos at the school. After the success of these activities, the blind and visually impaired girls performed some of the activities, such as building robots from kits, which the sighted girls did in Techbridge. While challenging, the girls found great satisfaction in successfully completing the activities, which allowed them to do such things as using tools, to which some of had never been exposed. The program has also included field trips, such as the trip to Sun Microsystems in Menlo Park, at which the guide for the girls was Don Hunter, a blind computer scientist with a degree from MIT. Having a role model with a disability similar to their own, and yet who had overcome obstacles to pursue a career in a leading edge technical field was a revelation to the girls. One observation made by Dr. Linda Kekelis, the Techbridge Project Director, was that
while almost all the sighted girls in Techbridge and previous programs with which she had been involved had some idea of what careers they wanted to pursue, many of the blind and visually impaired girls had never considered this question, or the possibilities open to them (Kekelis, 2001). Very little reliable data exists on college degrees granted to students with disabilities due to privacy concerns by universities, and the lack of a consistently applied definition of the term “disability.” However, it is recognized that persons with traditionally defined disabilities, such as blindness, deafness, or significant lack of personal mobility, form a significant portion of the population. (NSF, 2000) The few programs like Techbridge, which encourage persons from such groups to pursue new options in technical fields, serve a valuable, and definitely under-represented, portion of the available pool of technical talent for the future, and open exciting possibilities for extension of existing programs to encourage under-represented groups.

**Learning Mathematics Through Transactional Writing**

A very different program, which increases the number of under-represented students going into the available pipeline of engineering and computer science by increasing the number of students adept at mathematics, is the Transactional Writing program funded by NSF Grant No. HRD – 9554188, awarded to Miami-Dade Community College (Miami, FL). Studies indicate that males tend to perform better than females in mathematics, especially at higher levels, but this is not the case in writing. Yet engineering employers agree that both technical skills, such as a good understanding of mathematics, and communication skills, such as effective writing, are necessary for success in today’s technical career fields. The Transactional Writing program uses the traditional strengths of female students to both enhance their skills in math, and to reshape their attitudes toward it. Students use “transactional writing,” defined an expository form of writing used to develop, construct and express understanding (written for an audience such as a teacher), to express their understanding of significant mathematical concepts. This teaching and learning program enables the teachers to measure and correct students’ understanding of important concepts, and to provide feedback and opportunities for the development of writing capabilities. The program was conducted at three public middle schools and at the College, with male and female mathematics students in grades six through eight, and in college-preparatory and college level courses taught at the College. Similar sections of each course were used provide a control group against which results were compared. Data collected included both measures of attitude and math skills. Reliable and valid instruments were used, e.g., attitude was measured at all levels using Aiken’s Revised Mathematics Attitude Scale. The math portion of the Stanford Achievement Test was used to measure math skills on the middle school level, and for the college students, the Elementary Algebra Skills Test was used. Results indicate that the students at all levels in the sections using transactional writing improved both in math skills and in attitudes toward math when compared to students in the control group. While among males the link between writing and attitude is less striking, a clear and convincing link between both attitude improvement and skill level among females in the writing sections was indicated at both middle school and college levels. Additional information on this program can be obtained from Suzanne Austin at saustin@mdcc.edu. (Austin and Edwards, 2001)

**Adventures in Computers, Engineering, and Space (ACES)**

The University of Tennessee at Chattanooga, in partnership with Girls Incorporated of Chattanooga and the UTC Challenger Learning Center, is conducting a small experimental program entitled Adventures in Computers, Engineering, and Space (ACES) to encourage girls to consider careers in these fields, and to continue their educations in science and mathematics. ACES specifically targets girls entering the seventh or eighth grades (ages 12 – 14), with half of the participants being drawn from economically disadvantaged households and half from the general school population of Hamilton County, Tennessee. These groups are being tracked separately so that the success of ACES in influencing attitudes in each can be assessed. ACES includes a one-week residential
summer workshop for twenty-four girls each year. It was considered critical by personnel familiar with the economically disadvantaged segment of the population that ACES attempts to reach that the girls stay on the UTC campus, as many of them might never have been to a college campus or personally known someone who had attended college. The workshop provides space-related activities at the UTC Challenger Center including a "Mission to Mars," in which girls are divided into "mission control" and "away team" groups which must work cooperatively to complete the mission safely, design and launch of CO2 powered rockets, and design and construction of a "space station" designed by the girls, and built in the UTC pool using buoyant materials to simulate the problems of construction in weightless conditions. Engineering activities during the workshop include circuit construction, design and construction of programmable cars using Lego Mindstorms robotic materials, manufacturing process design, and construction of towers designed to hold a load for a specified time limit. Computer activities included simple programming tasks, generation of a disk with a computer version of the "hangman" game, web page design, and Computer Aided Drawing. The girls made a field trip to the Tennessee Valley Authority’s Raccoon Mountain pumped storage facility, and were taken on a tour including the power generation floor not usually open to visitors. In addition to technical activities, ACES attempts to address the "whole person" by including sessions related to nutrition, exercise, crafts, and exposure to positive female role models from the engineering and computer industries.

During the school year, follow-up activities occur approximately monthly to maintain the interest and knowledge created during the summer program. Follow-up activities include small design projects that encourage originality in solving problems with constraints, such as the "egg drop" competition, in which students were given design constraints by an industry "customer," made detailed design drawings and revisions, and tested their designs against criteria involving "egg safety," size, weight, and time required to release the egg after landing. Other follow-up activities for the girls include web page enhancement, circuits, field trips, and manning an engineering and computer exhibit during Engineering Week.

To widen the influence of the project, an ACES Fair, featuring hands-on engineering, computer, and space activities, will be conducted at selected elementary and middle schools, community centers, and other "targets of opportunity." The fair is designed to allow boys and girls of all ages to explore engineering and computer concepts through exhibits such as

• An electronic quiz on electricity, designed so that a bell rings when a student chooses a correct answer.
• An arrangement of ropes and pulleys, so that students can test the amount of force required to lift a constant load, both with and without the assistance of the pulleys.
• A bridge truss in which students can both apply and measure stresses.
• Design projects generated in the junior and senior design courses in the UTC engineering curriculum.
• An activity demonstrating relative size of the earth and the moon.
• A simple CAD activity, in which students can generate and print a drawing.
• A computer assembly activity in which an old computer will be disassembled and parts labeled with their names and functions. Fair participants will be allowed to explore the insides of the computer and become familiar with its inner-workings.
• A simple robot, which students can operate through a computer interface (this will use the Lego Mindstorm robots used for the residential summer program).

The combination of in-depth engineering, computer, and space activities, regular follow-up activities, and the ACES Fair provides a unique and considerable variety of approaches for such a new and small program, and one that could be replicated elsewhere on a relatively small budget. This project is being funded under the National Science Foundation Gender Equity Program grant number 00-03185. Additional information on ACES can be obtained from the author at Claire-McCullough@utc.edu or from the project website at http://www.utc.edu/aces.

Additional Programs

While only a few programs could be described in a paper such as this, some other programs of note include

• Georgia Tech’s Center for Education Integrating Science, Mathematics, and Computing programs, including workshops for students and teachers, a National Science Foundation sponsored program to increase "the proportion of women choosing to pursue technological fields by inspiring significant changes in science, mathematics, and engineering education across Georgia," and mentoring of K-12 students by Georgia Tech students with strong SMET backgrounds; (http://www.ceismc.gatech.edu/ceismc/programs/homepg.htm)
• The interCONNECTIONS™ series of books, being developed under an NSF grant to help girls "connect" to abstract concepts such as magnetic fields and atomic structure through use of metaphor and imagery (http://www.off-the-pageworks.com/);
• The UM-GIRL (Using Math: Girls Investigate Real Life) program, at the University of Michigan, aimed at minority and/or low-income girls who are under-performing in math (http://www.umich.edu/~umgirls/); and
• The Girls Tech program, a collaboration between Douglass College and the Girls Scouts of America, to developed a framework and criteria to "evaluate web sites, CD-ROMS, games, and other electronic information resources to judge their likely appeal to girls and young women and stimulate their interest in science and technology" (http://girlstech.douglass.rutgers.edu).
**Conclusions**

While many excellent programs exist, the problem of under-representation of women, minorities, and those with disabilities in the fields of engineering and computer science remains a serious one, and will grow more serious as society’s dependence on technology grows. The magnitude of the problem necessitates a concerted effort by school systems, universities, government, communities, and industry. Programs such as the ones detailed here, and the many others, which are being conducted both here and in other countries, can serve as models for all interested in developing programs to attract and retain under-represented groups to careers in technology.

**References**


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She also aids in the development of web pages and curriculum for the Electrical Engineering program. Dr. McCullough has over 20 years experience in engineering practice and education, including industrial experience at the Tennessee Valley Authority and the US Army Space and Missile Defense Command.

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- Application of Control Theory to Robotic Systems
- Probabilistic Risk Assessments and Reliability Studies
- Distributed Estimation
- Recruiting and Retaining Under-Represented Groups to Engineering

Dr. McCullough has published numerous papers in the areas of data fusion, intelligent control, and distributed estimation. A list of her publications can be found on her publications page, http://www.utc.edu/%7Eelecengr/clmc_pub.html.

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