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Abstract

In 2002, the College of Engineering at The University of Texas at Austin launched a three-year project funded by the GE Foundation to focus on the mathematics preparation starting at the middle school level. The project, Achievement in Mathematics for Engineering (AIM for Engineering), is designed to address a number of issues facing colleges of engineering:

- Engineering enrollments nationwide are flat or declining.
- Women and minorities are under-represented in engineering fields.
- Many students entering engineering programs are mathematically unprepared.
- Retention rates at many colleges of engineering indicate students are leaving due to the challenges of the first two years.

Major thrusts of the AIM for Engineering project include a professional development program for secondary algebra and calculus teachers, development of an online database of resources, high school outreach through school and campus visits, support for first year women and minority engineering students, and ongoing evaluation. Targeting eleven Austin public schools with high populations of under-represented students, the project combines the efforts of the College's Faculty Innovation Center, Information Technology Group, Equal Opportunity in Engineering, and Women in Engineering Program.

This paper explores the challenges we have faced and provide advice on avoiding potential pitfalls. Some of the issues we examine include:

- Working with local schools
- Developing classroom-ready lessons
- Dealing with the disengagement and departure of team members
- Making adjustments to deal with unanticipated outcomes
- Replication and sustainability

The AIM for Engineering project is a catalyst for cooperation among participating organizations within the College. While we have experienced both successes and disappointments, we have learned many valuable lessons that can be applied to future endeavors.

Need

The United States may face a shortage of engineers in coming years. The National Science Board's *Science and Engineering Indicators 2002* [1] cites these trends:

- Undergraduate engineering enrollment declined by more than 20% between 1983 and 1999.
- Graduate engineering enrollment peaked in 1993 and continues to decline.
- The total number of retirements among science and engineering-degreed workers will increase dramatically over the next 20 years.
- Between 2000 and 2010, science and engineering jobs are projected to increase by 47% compared with 15% for all occupations.

Women and minorities represent a vast talent pool that can be attracted into engineering fields. Women, who comprise about half of the general population, received less than 21% of the engineering bachelor degrees awarded nationwide in 2000.[2] At the College of Engineering at the University of Texas at Austin (UT), 23% of undergraduate engineering degrees were awarded to women for the 2002-2003 academic year.[3] Women account for 22% of undergraduate enrollment in UT engineering programs in fall 2003.[4] Under-represented minorities accounted for less than 13% of the engineering bachelor degrees awarded nationally in 2000.[2] At UT, underrepresented minorities accounted for 17.5% of the undergraduate enrollment in engineering programs in the fall of 2003.[4] The National Action Council for Minorities in Engineering rated the UT College of Engineering seventh in the graduation of minority engineers in 2001.[5] Even with this strong record, we strive to attract more minorities into our engineering programs.

Retention is a key issue related to graduation rates. Science and engineering fields report the lowest retention rates among all academic disciplines. Approximately 50% of students entering higher education in the sciences or engineering change majors in the first two years. Moreover, women and underrepresented minorities leave science and engineering programs at a higher rate than men and non-minority students.[6] For the 2002-2003 academic year at UT's College of Engineering, first year retention of women (69.4%) and minorities (69.4%) was lower than retention of all engineering students (74.3%). In year two, women fared better with a retention rate of 59.3% compared to 58.5% for all engineering students, but the second year retention rate for minorities dropped to 46.7%.[7]

Academic readiness is a crucial factor that affects retention, as well as the ability to enter engineering programs. Success in engineering programs requires advanced mathematics preparation. A recent entrance policy change at UT's College of Engineering requires that students be "calculus-ready" to be admitted to an engineering major. In 2000, however, only 17% of U.S. twelfth graders achieved a mathematics skill level regarded as proficient by a national panel of experts. An even smaller minority of twelfth graders – 2% – achieved an advanced skill level in mathematics.[8] The performance of U.S. students in science and mathematics becomes increasingly weaker at higher grades. According to the *Third International Mathematics and Science Study* (TIMSS), U.S. twelfth graders scored below the international average and among the lowest of the 21 participating nations in both mathematics and science.[9]

The shortage of academically qualified secondary students is a difficult hurdle that must be overcome.

For these reasons, and others, there is a growing interest in K-12 mathematics and science initiatives among colleges of engineering. In her plenary address at the 2003 ASEE Conference, Shirley Ann Jackson offered the following recommendation:

> We [engineering educators] must be prepared to intervene earlier, and to supplement what the primary and secondary schools offer these young people, or to seek out other ways to assure that they are prepared, academically, to undertake engineering study.[10]

UT's College of Engineering seeks to make an impact in our own community. The Austin Independent School District (AISD) is a large school district that services a student population of 78,689 in urban Austin, Texas. AISD manages 107 campuses, including 74 elementary schools, 17 middle schools and 12 high schools, and has a staff of over 10,000 employees, including 5,388 teachers.[11] In 2001 when the College was asked to submit a proposal to the GE Foundation, statistics for the 1999-2000 academic year were available. The picture has improved in the interim, but at that time six of ten AISD high schools were rated as low-performing by the Texas Education Agency.[12] The same year, only 68.4% of economically disadvantaged students in AISD passed the mathematics portion of the state mandated Texas Assessment of Academic Skills (TAAS).[13] Participating in the GE Foundation's Math Excellence initiative provided an opportunity for K-12 outreach that is aligned with the University's mission of service to the community.

AIM for Engineering

In December of 2001, the GE Foundation awarded UT's College of Engineering a grant of $483,000 over three years. The GE Foundation, the philanthropic organization of the General Electric Company, invests in improving educational quality and in strengthening community organizations around the world. All told, GE, the GE Foundation and GE employees and retirees contributed over $120 million to community and educational institutions last year. A continuum of targeted initiatives supports increased educational opportunity from pre–college through higher education. The GE Foundation's Math Excellence program is a K–16 initiative focused on strengthening math skills of students from under–represented backgrounds, leading to greater participation in engineering, information technology, and quantitative business careers.

The project came to be known as Achievement in Mathematics for Engineering or simply AIM for Engineering. Launched in the first quarter of 2002, the project strives to boost the number of underserved students from specific local schools who are mathematically prepared to enter UT's engineering programs. Within the AISD, the project targets eleven schools with high populations of traditionally underserved students. Additionally, the grant supports underserved engineering undergraduates who may be struggling with the demanding requirements of the program. Specific objectives of the project are to increase the number of students completing algebra by the end of eighth grade and calculus by the twelfth grade, increase the number of underrepresented students entering UT-Austin's engineering programs, and improve retention of first year undergraduate women and minority students.

Thrusts, Participants, and Current Status

AIM for Engineering is a multi-faceted project that brings together several diverse groups within the College and the community. The Faculty Innovation Center (FIC) coordinates and manages the project, serving as the central hub for the various activities and participants. Within the College, the FIC's purpose is to support instructional innovation and excellence by providing media, instructional, and faculty development services.

We are now entering the third and final year of the project. With the exception of data collection which will extend into the spring semester of 2005, all activities will be completed by the end of this calendar year. The major thrusts of the project, as well as contributing organizations and individuals, are described below.

Teacher Professional Development Program

The AIM for Engineering project has created a customized professional development program for secondary math teachers designed to help them better integrate engineering and science applications into their classroom experiences. Dr. Richard Crawford, a mechanical engineering professor, is a founder of Design Technology and Engineering for America's Children (DTEACh), a grassroots science-mathematics-technology teacher education project for elementary school educators. With a 12-year history of involvement in K-12 outreach and teacher development, Dr. Crawford is leading the AIM for Engineering teacher professional development effort. The FIC is also contributing to AIM's teacher professional development component by providing instructional design and media development services. Mechanical engineering students and secondary math teachers round out the AIM teacher professional development team.

A series of eight professional development workshops were offered on Saturdays over the 2002-2003 academic year. Dr. Crawford led the workshops with the help of a graduate teaching assistant. Twelve teachers attended one or more of the four algebra workshops and nine teachers attended one or more of the calculus workshops. Teachers who attend the professional development program receive Continuing Professional Education (CPE) credit, equipment (such as gear kits, water rocket launchers, and toy catapults), as well as a stipend.

The 2002-2003 workshops were loosely structured. Each workshop was centered on a mechanical device. Many of the printed documents that teachers received had been recycled from other workshops and contained extensive background information. Teachers also received printouts of the professor's notes and calculations on the electronic whiteboard.

In a focus group held in May 2003, teachers indicated that they needed more structured "classroom ready" materials. Over the summer of 2003, two high school teachers, in collaboration with the FIC instructional designer, revised and enhanced the activities, resulting in teacher notes, setup guides, and student handouts for three algebra activities and two calculus activities. All documents are accessible at http://www.engr.utexas.edu/aim/curriculum/#hands. The FIC technical team developed an online question bank that allows teachers to generate customized homework, quizzes, or tests (see http://www.engr.utexas.edu/aim/questionbank).

Based on our experience in 2002 and input from teachers, we offered only two professional development workshops in the fall semester of 2003. Each workshop covered two activities. Thirteen teachers attended the algebra workshop and four teachers participated in the calculus workshop. A focus group will be held in April 2004 to receive input from the teachers on their experience with the activities.

Additional activities are currently in development and will be ready for summer 2004. In order to involve more teachers, we are planning a summer institute rather than Saturday workshops. While we have had fair representation of high school teachers, our goal is to recruit more middle school algebra teachers for the summer institute.

Online Database of Resources

An online database, known as the Learning Grid, provides access to resources that supplement math learning and increase interest in engineering professions. Developed by the College's Information Technology Group (ITG), the web-based tool allows parents, teachers and students to search for K-14 educational programs and resources available through UT and other sources. The catalogue includes over 460 programs and can be navigated by various criteria, such as grade level, subject interest, location or types of programs. Users can rate the programs and resources they use. The site is available to the public at http://www.engr.utexas.edu/k14.

In a usability test conducted in January 2003, the site received high ratings for ease of use and the availability of a wealth of information found in a central source. Development of the Learning Grid is complete; only maintenance and updates are required in 2004. Early completion of the database leaves an expected funding surplus this year. The GE Foundation has approved redirecting the surplus funds to boost pre-college outreach initiatives.

Pre-college Outreach

An important goal of this project is to attract high school students to study engineering. The College's Equal Opportunity in Engineering (EOE) program and Women in Engineering Program (WEP) have joined forces to coordinate high school and campus visits. Representatives from undergraduate engineering organizations, such as Society of Women Engineers, National Society of Black Engineers, Society of Hispanic Professional Engineers, and the Engineering Student Ambassadors are participating in the high school visits to answer questions about college student life and engineering opportunities. High school students visit our campus for tours and special events. A group of 60 tenth graders visited our campus in September 2003 and toured the engineering complex, visited a residence hall, and heard panel of engineering students. WEP and EOE also invite high school students to UT for special events, such as Explore UT, a campus-wide open house event featuring lectures, displays, demonstrations and hands-on activities for all ages.

Due to early completion of the online database, $26,000 will be redirected in 2004 to enhance pre-college outreach efforts. Previous outreach efforts focused only on three high schools. The additional funds will allow expansion of outreach activities to all five target high schools and six middle schools. WEP and EOE will leverage several of the existing programs they offer to inform pre-college students about engineering careers and attract women and minorities to UT's College of Engineering. Programs such as Girl Day, Un Sabado Gigante, Minority Introduction to Engineering (MITE), World of Engineering, Consider Every Option, and Your Opportunities are Unlimited (YOU@UT) give students the opportunity to interact with industry representatives and engineering faculty and students. WEP and EOE report that students from the target schools have participated minimally in these programs in the past. The additional AIM funding allows WEP and EOE to direct a concerted recruiting effort toward the target schools. The extra funding will also be used to provide transportation to and from campus events, as well as providing copies of ASEE's "Engineering Go For It!" publication to high school 2000 high school students. We expect the intensified pre-college outreach to greatly increase the impact of the project at the target schools.

Undergraduate Support

Support for engineering undergraduates encompasses several programs targeting first-year engineering students. A special undergraduate mentoring program pairs first-year women and minority students with upper-division peers. Mentors provide guidance and assistance to ease the transition into a four-year engineering program. First year students can also participate in design competitions sponsored by the AIM for Engineering project. As many as 100 first year students participated in each of the four design competitions in 2003. Finally, a series of skills development workshops is available to first-year students so they will be prepared to succeed at UT. Workshop topics include: Introduction to the Engineering Career Assistance Center, Career Fair Preparation, Women's History: Women in the Air, the MBA Option, and the Academic Leadership Institute. Eight workshops will be offered during the 2003-2004 academic year. Each fall 2003 workshop was attended by between 20 and 56 students.

Evaluation

Evaluation is an integral part of this project and includes both formative and summative components. The FIC is responsible for data collection and contributes to the national cross-project evaluation effort conducted by Campbell-Kibler Associates for the GE Foundation. With the help of WEP and EOE, the FIC tracks the number of people participating in pre-college outreach events and undergraduate support programs. Enrollment data for women and minority students in UT Engineering programs will be examined to assess retention.

The FIC is collecting data on the number of underserved students completing algebra I and calculus at the target schools over the three years of the project. Students also respond to a brief survey on their feelings about mathematics and the way it is taught. Teachers complete pre and post surveys and are asked to participate in focus groups. Algebra and calculus students complete surveys at the end of each school year. In addition to formal data collection, we talk to teachers at every opportunity to learn more about what works for them.

Lessons Learned

Both formal data collection and informal information gathering have been valuable in making formative adjustments and discerning the many lessons we have learned from this project.

Working with Schools and Teachers

There is little doubt that the public school environment is very different from a university environment. We have come to realize how important it is to understand the unique concerns of teachers. Learning to navigate within the local school system can take time.

1. Work at every level to get teacher involvement. Disseminate information about your program to the school district's central administration, principals and vice principals of the schools, math department chairs, and individual teachers. Make sure the people at the top know about your program. Ask them to encourage teachers to participate. Math department chairs can be very helpful in getting information to the right teachers. Word-of-mouth can be powerful in spreading enthusiasm among teachers.

2. Offer incentives to get participation for voluntary programs. Teaching in the K-12 arena is rarely a path to fame and riches. Even small rewards are appreciated, especially if teachers have to spend evening or weekend time in your program. We offered stipends, equipment, and Continuing Professional Education (CPE) credit.

3. Offer incentives to complete program requirements. To assure that teachers implement our activities in class and to help us with data collection, we also offer a financial incentive at the end of the school year.

4. Listen to teachers. Hold focus groups with teachers. Ask teachers what they need and want, but do not expect them to speak with one voice. Be prepared to get an earful about issues that are beyond the scope of your project. At the algebra I level, teachers told us they need activities that combine data gathering, graphing, and calculation, particularly related to linear and quadratic functions. This helped us set our initial direction with regard to developing classroom activities.

5. Build a sense of community. Small efforts can count for a lot. Communicate with people on a personal level. Use email to share humorous or interesting information with teachers. Provide snacks and meals, especially for all day events. Eating is a social lubricant. Anything that makes people feel comfortable and appreciated can help create a positive and caring environment.

Developing Classroom-ready Resources

Drawing on a wide range of research on effective learning, the National Learning Infrastructure Initiative (NLII) developed a core set of deeper learning principles. According to this report, deeper learning occurs when the learning experience is social, active, contextual, engaging, and student-owned.[14] We attempted to embody these principles in developing instructional activities and classroom-ready resources.

1. Include an instructional designer on the development team. The role of instructional designers is often misunderstood. Classroom teachers may consider themselves to be instructional designers, but the skill set is very different. We strongly recommend finding someone with formal training or a degree in instructional design to assist in developing classroom resources.

   Our ever-evolving team has included several teachers, an instructional designer, an engineering professor, and two engineering students. Teachers bring knowledge of the subject matter, target audience, classroom environment, local curriculum, and state standards. The instructional designer provides expertise in learning science, instructional methods, assessment, as well as experience in developing instructional materials. The engineering professor and students provide subject matter expertise the context of practical applications for mathematics concepts and skills. Each person's contribution is vital to the outcome.

   Without the influence of an instructional designer, we found that the lessons tended to rely on more traditional methods (telling rather than doing) and often moved too quickly to doing calculations. The instructional designer kept the lessons focused on an active learning approach and helped structure them to build from concrete experience to abstract understanding.

2. Provide a concrete context for learning. One of the most valuable contributions the engineering community can make to K-12 education is providing a context for learning. Math is often taught at an abstract level that is disconnected from any real-world purpose and not grounded in observable experience. Many notable learning theorists support the idea that deeper understanding occurs when learning is contextual and involves real-world problems.[14] Learning is concrete and students understand ideas in the context of a conceptual framework. Real-world problems provide meaningful tasks and opportunities for exploration, judgment, and practice. Engineering is a wonderfully rich domain for providing a context and purpose for doing math.

   Each of the instructional modules we developed involves a mechanical device, such as a catapult or water rocket launcher. These devices provide a context for making observations, recording data, and doing calculations. Whether determining where to position a catapult to hit a target or calculating the optimal volume of water to launch a rocket, the devices give students a framework for understanding and a reason for learning.

3. Minimize the equipment setup requirements for the teacher. Mechanical devices support understanding and increase student motivation. Using these devices, however, often requires significant setup time for the teacher. The first version of one of the algebra activities called for several Lego pull-back cars. Each car had to be assembled and some had more than 100 pieces! Although the Lego cars had different motors, which

allowed for some relevant comparisons, we were able to easily adjust the activity to use Tonka Monsters, which require no assembly time. Teachers appreciate this efficiency. Similarly, one of the calculus modules initially provided supplies and required teachers to build a water rocket launcher, which took five to six hours. In the second iteration, we provided commercially-produced water rocket launchers. They were costly, but allowed us to spend more time focusing on the math with the teachers. In turn, the teachers were able to get straight to the activity with their students.

4. Provide support for implementing the activity. Hands-on learning activities generally take more time than traditional classroom practices. Some teachers may be uncomfortable with the noise level and disorderly nature of this type of learning. It is important to provide a range of support to make it easy for teacher to implement the activities in class. Each activity that we developed includes the following:

    - An overview allows the teacher to quickly grasp the structure of the activity. We used a pre-lab, lab, and post-lab format. The initial teacher document provides a brief description of the each phase.
    - Learning objectives tell the teacher the skills that students will learn.
    - Equipment list, setup procedure, and timing guidelines help the teacher prepare for the activity.
    - Teaching suggestions offer guidance on managing student groups and leading discussions.
    - Student handouts guide students through the activities, collecting data, generating graphs, and doing calculations.
    - An online question bank is available to support assessment. Teachers can select questions and generate customized homework, quizzes, or tests.

5. Provide integration with curriculum. Activities must be aligned with state standards and textbooks. Schools are under tremendous pressure to meet state standards and cover all required content. Teachers will not use activities that do not support state and local requirements. Our materials list the Texas Essential Knowledge and Skills (TEKS) supported by each activity as well as correlation to the textbook used in our school district.

Managing the Project

In addition to tracking spending and reporting to the project sponsor, the project management function involves coordinating the diverse activities of the project, monitoring progress, and gaining consensus when adjustments must be made.

1. Align the grant/project year with the fiscal year. The annual reports for our project are based on the January to December calendar year. University financial reporting systems, however, work on a September to August fiscal year. You can increase your reporting efficiency if you can align the grant reporting timeframe with your organizations financial reporting system.

2. Understand all of the sponsor's requirements. Some of our sponsor's requirements took us by surprise. We had planned on doing the project evaluation. After the project was launched, however, we started receiving information about cross-project evaluation requirements that had not been delineated earlier. We were required to collect data for each intervention using prescribed online forms. We had to adjust our planned evaluation in order to meet the cross-project evaluation requirements.

3. Allow unresponsive team members to disengage. An organization that was originally slated to contribute to the project became unresponsive just a few months after the project was launched. They would not respond to phone or email messages and gave no indication that they planned to engage in the activities outlined in the proposal. In all fairness it should be stated that this organization had recently experienced a staff reduction and was implementing some rather demanding initiatives. This organization seemed to be stretched too thin to participate in the project as planned. Fortunately, we were able to make adjustments and take up the slack among other team members. We still keep the disengaged organization informed about the project and continue to invite their participation. If you are faced with an unresponsive individual or group, try to find out the underlying cause and keep lines of communication open.

4. Redirect funds as circumstances change. There are various reasons why funds may need to be redirected. Several circumstances in our project have resulted in shifting funds from one area to another. As mentioned previously, one organization was not able to participate as planned and hence the funds could not be distributed to them. At the same time, we discovered that teachers commonly receive a stipend for attending professional development programs. We had not included a budget item for stipends. We were able to redirect funds from the disengaged organization to teacher stipends.

   In another area, the math resource catalogue system was completed under budget and ahead of schedule in year two, resulting in a funding surplus. With the approval of our sponsor, we redirected $26,000 and were able to dramatically increase the pre-college outreach activities, which had been under-funded.

Replication and Sustainability

Large-scale transformation is difficult to accomplish in just three years. We hope the impact of this project endures beyond the scope of the grant. To leave a lasting legacy, it is important to establish systems that are replicable and sustainable.

1. Do not spend money just because you have it. Our project had a very generous budget to buy equipment for teachers to use in the classroom. Initially, we planned to purchase several rather expensive application kits for each teacher in our professional development program. Later, we made adjustments so that the activities require less expensive equipment. Lower equipment costs make it more feasible for others to replicate our activities without such generous funding.

2. Be cautious about making long-term plans for start-up organizations. One of the implicit goals of our project was to support the establishment of a K-14 Learning and Research Center within the College of Engineering. At the beginning of the project, an "executive on loan" was dedicated to seeking funding to establish the center. Project participants anticipated the K-14 Center would have an office, staff, and sustainable funding within a year or two, and would be coordinating several additional K-12 outreach projects. With regard to the AIM project, the K-14 Center was expected to coordinate development of the math resource catalogue and ultimately "own" the database, updating it on an ongoing basis.

   For a number of reasons, including the general downturn in the economy, the "executive on loan" was not able to secure sufficient funding to hire staff and establish the center. The K-14 champion ultimately left the University and the expectation of establishing the K-14 Center was put on hold. We are currently seeking a long-term "home" for the database and hope that it will be absorbed into a larger university-wide initiative with similar goals.

3. Confirm your institution's commitment to K-12 endeavors. K-12 outreach has little chance of being sustainable if it is not supported by the higher education institution's administration. In recent years, K-12 issues have become increasingly important across our entire campus. Both UT and the College of Engineering have expressed commitment to K-12 outreach. We are fortunate to be in an environment that values service to the community. Along with teaching and research, public service is reviewed for tenure and promotion, so there is some incentive for faculty who choose to be involved in K-12 outreach. Several organizations and individuals within the College are involved in various K-12 projects and coordination of K-12 initiatives is not centralized. Even though our College recognizes the need and expresses commitment to K-12 outreach, the means by which we will support K-12 endeavors on a long–term basis is open for debate.

   Before engaging in K-12 outreach endeavors, it is important to confirm your institution's commitment. Does your college or university consider K-12 outreach to be part of its mission? What organization within your institution will take responsibility for K-12 initiatives? How will faculty and staff be rewarded? Institutions will be most successful when the commitment to K-12 outreach is clearly defined.

Conclusion

There is a tremendous need for K-12 outreach to increase the number of students who are mathematically prepared to pursue science and engineering careers. We face a dilemma, however, with regard to the role that colleges of engineering can and should play in addressing the need. In the higher education arena, K-12 outreach is peripheral to the core mission.

With support from the GE Foundation, UT's College of Engineering launched the AIM for Engineering project to enhance mathematics preparation at several schools within Austin and to improve undergraduate retention. Although data collection and analysis will not be complete until the summer of 2005, we can list several benefits from the project.

- AIM for Engineering has been a focal point of communication and collaboration among the participating organizations within the College. FIC, ITG, WEP, and EOE have all benefited from the increased collaboration.
- We have established a network of contacts at Austin schools that will facilitate ongoing outreach to K-12 and aid communication about future projects and events.
- A set of learning activities have been developed taking an active, hands-on approach that is grounded in research. These activities are available for others to use.
- The teachers who have participated in our workshops thus far have expressed enthusiasm about using the engineering-based activities with their students.

We hope to achieve a saturation level at the target schools so that all algebra and calculus teachers are trained on AIM for Engineering activities. Evaluation efforts are in progress to assess the impact on students. While we have every reason to believe the AIM for Engineering project will increase students' interest and proficiency in mathematics at the target schools, we will be satisfied with modest improvements. Three years is a very short time to effect systemic change, even at a limited number of schools. Our efforts are just one factor in a complex environment.

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