Creating CHANGE in Engineering Education

A Model for Collaboration Among Institutions

BY CAROLYN PLUMB AND RICHARD M. REIS

Engineering betters the lives of the community and world through knowledge and construction. ... I didn't think engineers did that much stuff.
—An American-Indian student at Montana State University

The United States, as well as the rest of the world, will face critical civil, environmental, energy, communication, manufacturing, and health-care challenges in the coming decades, and more scientists and engineers will be needed to address those problems. The number of jobs in the U.S. labor force requiring science and engineering skills, in fact, is growing almost five percent per year, while the rest of the job market is growing at just over one percent.

Ironically, at the same time that anxiety exists concerning how to increase U.S. engineering enrollments, many potential engineering students

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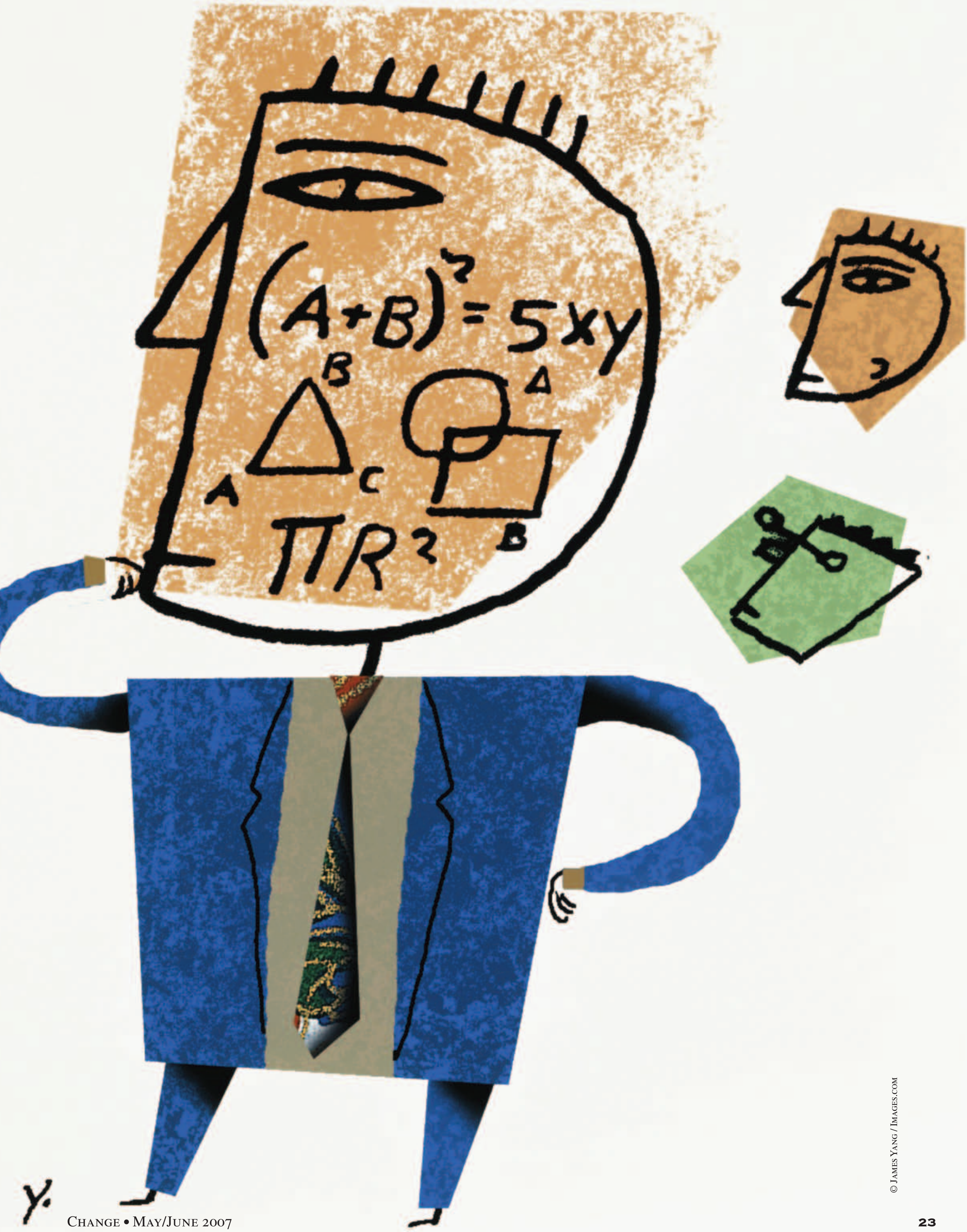

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are wondering if most engineering jobs in the future won't be sent offshore by U.S. employers to lower-wage engineers in places such as India, China, and Eastern Europe. And indeed, according to chemical-engineering educator Richard Felder, "The relentless movement of industry to computer-based design and operation and off-shoring of skilled functions and entire manufacturing operations is not about to go away. On the contrary, as computer chips get faster and developing countries acquire greater expertise and better infrastructure, the movement will inevitably accelerate."

Yet, although IBM has 40,000 employees in India, it has significantly increased its hiring in the United States over the last five years.

What does this say about the need for U.S.-trained engineers? Felder believes that instead of just concentrating on analytical and problem-solving skills, we need to develop in American engineering students skills such as research creativity, entrepreneurial risk-taking, multidisciplinary thinking, and the strong interpersonal and language skills that will enable them to function as self-directed, collaborative learners long after they leave the classroom.

These U.S.-based "global engineers" must have strong technical backgrounds but also "cross-boundary" skills such as working across disciplinary, organizational, cultural, and time/distance barriers, capabilities that will give them a competitive advantage over their foreign counterparts. It is here that the increasing diversity of the college-age population can be a real plus, even while it presents challenges to increasing the number of U.S. science and engineering graduates.

In response to these pressures and the need for reform in engineering education, in 2003 the William and Flora Hewlett Foundation initiated a comprehensive project, the Engineering Schools of the West Initiative (ESWI), to improve engineering education by means of the collective efforts of nine primarily bachelor's- and master's-granting institutions in the Western United States. After four years, the initiative already is having a significant impact at the schools involved, illustrating how collaboration and communication among the institutions have facilitated important changes in engineering education. We believe this program can serve as a model for other collaborations among institutions, not just in engineering but also across the entire curriculum.

Reform in engineering education is necessary for the recruitment and retention of a diverse student body. While overall enrollment in U.S. higher education is expected to continue rising over the next decade due to increases in the U.S. college-age population, according to data from the National Science Board the percentage of white students is projected to decline from 66 percent in 2000 to 58 percent by 2020, while the percentage of Hispanics is expected to increase from 15 percent to 22 percent and the percentages of blacks and Native Americans to remain steady at 14 percent and 1 percent respectively. Since whites have historically been more likely than non-Asian minority students to earn science and engineering degrees, we need to encourage more Hispanics and other minorities to enroll in and graduate from science and engineering programs.

There is an increasing need to create an environment in which a more diverse group of students has a fair chance at obtaining an engineering degree.

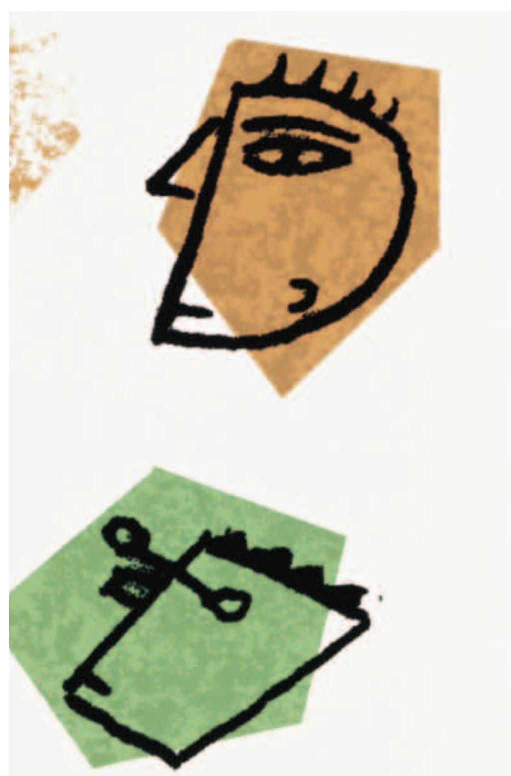
Meanwhile, while the percentage of women enrolled in undergraduate science and engineering programs is increasing, there are significant differences by discipline. In 2000, women earned 21 percent, 28 percent, and 41 percent of the bachelor's degrees in engineering, computer science, and the physical sciences, respectively, while they earned 77 percent of the bachelor's degrees in psychology, 59 percent in biological sciences, 54 percent in social sciences, and 48 percent in mathematics. In 2000, among the nation's 24-year-olds, the percentage of minorities earning science and engineering bachelor's degrees was 2.5 percent, while the percentage in the population as a whole was 5.7.

Those figures reflect not only many institutions' lack of success in recruiting a diverse student body, but also the degree to which students, when they enter engineering programs, are differentially at risk. About two thirds (68.3 percent) of majority freshman who enter an engineering program graduate with a bachelor's degree in engineering. A little over one third (37 percent) of minority students do the same.

So there is an increasing need to create an environment in which a more diverse group of students has a fair chance at obtaining an engineering degree. This environment will need to take into account a variety of learning styles, as well as gender and cultural differences.

The Initiative

The three- to five-year grants-support programs ranging from summer projects that target high-school



Schools in The Initiative

- Boise State University
- Colorado School of Mines
- Montana State University
- New Mexico State University
- Northern Arizona University
- Oregon State University
- University of Nevada, Reno
- University of Utah
- University of Wyoming

students from traditionally underrepresented groups, to team-based collaborative learning courses that mirror how engineering is done in industry, to efforts to help engineering students understand the ethical issues and responsibilities of professional engineers.

Institutions were chosen to participate in the project in part for their potential "multiplier effects"—that is, the likelihood that changes at the institution would stimulate similar changes in engineering programs at other colleges and universities. They were also selected for their commitment to rigorous assessment and their ability to sustain the effort over the long term. Finally, the foundation picked programs that were willing to collaborate in tackling such issues as new ways to provide students with a global orientation to engineering problems.

Recruitment and Retention Best Practices

The primary goal of the ESWI institutions is to increase the recruitment and retention of engineering students, particularly women and under-represented minorities. Recruitment is important to engineering not only because fewer students are choosing to study engineering at a time when American industry needs more and better engineers to help the country stay economically competitive, but also because there are almost no K-12 analogs to engineering, which exist for most other college majors. Thus, younger students do not know much about what engineers do or how they contribute to society.

Of course recruitment is not enough. Students leave engineering programs for a multitude of reasons, including not understanding how their foundation courses will apply to their engineering program; a lack of preparation for the rigor of the curriculum; not feeling like they are part of a community; and learning styles that are not compatible with the pedagogies typically used in engineering education. The retention activities of the ESWI schools are geared toward addressing those issues.

After three years of developing recruitment and retention programs and assessing the results, our collective understanding of best practices in these areas may be helpful for other schools undertaking similar initiatives, in or outside of engineering.

Recruitment Strategies

The ESWI partners have tried many approaches to recruiting a larger and more diverse group of students, including connecting with K-12 teachers by developing instructional materials, holding summer engineering camps at the institutions, and taking the message about what engineering is to the K-12 community. Results so far show that connecting with K-12 teachers in various ways and holding summer camps for middle- and high-school students may bring institutions the most "bang for the buck."

Connecting With K-12 Teachers. One approach to enhancing recruitment is connecting with K-12 teachers. For example, at the University of Wyoming, the Teaching and Doing Math and Science through Engineering Program, inspired by ESWI and funded in cooperation with the U.S. Department of Education, provides K-12 teachers with contemporary engineering topics and technology as vehicles for generating math and science modules for their classrooms. The modules are helping teachers and students understand engineering and how it connects with everyday life. For example, Paul Crips, a middle-school science teacher from Cheyenne, Wyoming, participated in the workshop in 2004 and now has distributed these ideas across his school district. In spring 2006, he and faculty at the university were awarded a U.S. Department of Education grant for the implementation of inquiry-based science and math curricula in seventh-grade courses, beginning in the 2006-2007 academic year.

At Montana State University, the ESWI-funded Designing Our Community seminar, taken by all American-Indian engineering students each semester, has morphed into a spring-semester service-learning course. Students in the course develop engineering activities that help teachers teach Montana's math and science standards for grades five through eight. This approach positively affects three different groups: the MSU engineering students, who are trying to understand how they can apply engineering in their lives; the teachers, who are looking for active and engaging ways to teach math and science; and the young students, who discover a real-world application for math and science content. One engineering student commented in the course evaluation that "the seminar helped me as an engineer by demonstrating an approach to teaching others about engineering in an interesting and inclusive manner."

At Boise State University, as part of the "ripple effect" from the ESWI, engineering and education faculty have collaborated on a teacher-education course that focuses on using engineering to teach science and math at the elementary- and middle-school levels. The course has been offered for four consecutive springs, and enrollment has increased steadily each spring. Students in the teacher-education course report that their preconceptions about engineering were often misconceptions; they also report that they now view problems in labs from a more practical point of view and do not feel as intimidated about integrating engineering activities into the elementary curriculum.

Summer Camps for Middle- and High-School Students. Another successful approach to recruiting is summer camps for middle- and high-school students. This approach is more resource intensive than making connections with K-12 teachers, but it can be rewarding for the faculty, staff, and students involved in the camps.

At New Mexico State University, ESWI funds help support Pre-College Student Experiences in Science, Mathematics, and Engineering (PREP), an eight-week, academically intense summer program that prepares students for careers in science, engineering, and mathematics. The program includes courses and seminars; field trips to places where science, engineering, and mathematics are used on a daily basis; and interaction with college-age mentors. Last year, 76 percent of the PREP participants were underrepresented minorities and 55 percent were female. Over the decade that PREP has been in place, 511 students have successfully completed the first component of the program. A recent survey of these past PREP students showed that over half (52 percent) had gone on to major in science, engineering, or mathematics.

The University of Wyoming has developed summer workshops that invite a broad spectrum of prospective students and K-12 educators onto campus to learn more about engineering, math, and science. The Middle-School Girls Camp provides a week-long residential experience for girls in the sixth through eighth grades, with hands-on investigations in fields such as electronics, robotics, and Global Positioning Systems with mapping. Nine girls attended the first camp, 12 attended the 2005 camp, and 11 the third camp in the summer of 2006. The girls were surveyed before and after each year's camp, and each year the pre- and post-assessments have shown a significant increase in participants' understanding of what engineers do, as well as a significant increase in their desire to pursue engineering. In addition, the girls report an increased likelihood of continuing with technical mathematics and science courses in junior high and high school.

Similar experiences are provided for 30 high-school students. Participants had expressed a prior interest in engineering, but they have reported that the summer camp increased their interest in studying engineering at the University of Wyoming. All girls have said that they would recommend the experience to a friend.

Retention Strategies

A key issue in retention is lack of student preparation for the rigorous math and science curriculum found in engineering. ESWI schools are addressing this issue with various approaches, which include community-building, student-centered pedagogies, engineering courses in the first two years of college, on- and off-campus internships, and a humanitarian-engineering minor.

Community Building. Approaches to creating community are many and varied, as well as relatively inexpensive and effective. Oregon State University has developed a Transitional Learning Community (TLC) for participants in the Women Engineering Their Futures program. The community provides a support structure, combined with enrichment activities led by upper-division female student peer-leaders. The pilot was so successful that beginning in autumn 2005, all students in two of the college's introductory engineering courses were assigned to a learning community.

In the Designing Our Community (DOC) program at Montana State University, American-Indian students are required to attend a one-credit course that meets once a week. During the fall version of the seminar, students hear presentations from engineers who are role models, including American Indians, and learn more about what engineers do from engineering faculty. One student noted that the presentations showed him "more ways that Natives can be successful on reservations." Students in the program sign a contract that requires them to attend the seminar, spend four hours per week in the Engineering Minority Program Student Center, attend school full time, and maintain a 2.5 grade point average. In return, they receive a small monthly stipend—which, as one student commented, "has allowed me to concentrate on my studies. ... It also gives me independence from my parents financially. ... I get confidence from this independent feeling as well as relief, because my parents can't afford to support me." During the 2004-2005 academic year, students in the program remained in college at a higher rate (67 percent) than did American Indians generally on the MSU campus (60 percent).

Student-Centered Pedagogies. A related approach to improving retention is adopting student-centered pedagogies. Systemic change in pedagogy is difficult to achieve but not resource intensive. Several of the ESWI schools have made this area of reform a focus.

For example, Oregon State University has moved to student-centered pedagogies by implementing a curriculum based on active and cooperative learning, using the college's new wireless network. Early efforts focused on developing active-learning approaches in three courses in one department. Those approaches included classroom polling about course content, an e-minute paper (writing a brief answer to a question), an e-muddiest point (stating the least clear point from the day's lecture), and an e-one-sentence summary of lecture material. In addition, a large second-quarter freshman engineering course, which had been taught using a traditional lecture format combined with a smaller once-a-week lab, was given a facelift by creating for nearly every lecture some small-group, active-learning exercises that are submitted electronically at the end of the lecture. Attendance in the course sections improved from the typical 50 percent to 75 to 90 percent. Further evaluation indicates that student learning, as measured by exam scores, also improved as a result of the innovations. These innovations have been shared with other ESWI schools through the annual meeting of program participants and a Web site.

Engineering Courses in the First Two Years. Other ESWI schools are attacking retention by way of curricular reform, which is a more expensive and long-term approach. Improving student success in prerequisite mathematics and science courses is not enough. Students need opportunities to apply what they learn in these foundational courses to engineering problems. Most engineering programs now include some introduction to engineering in the first two years, but in the vast majority of programs, foundational skills are not fully integrated with engineering applications. It is difficult to ask students to, as one faculty member put it, "plow through the tough stuff for two years, and then we'll give you the engineering goods."

Boise State University (BSU) has worked on several strategies to integrate math with engineering applications in the freshman year. Faculty have developed freshman-level modules that integrate math, physics, chemistry and broader issues of engineering relevance such as ethics, research, and sustainability. These curricular efforts have been shared across the ESWI schools via a Web site, as well as through conference presentations and proceedings. Eight modules have been developed; the one people most frequently request information about is "Peanut Butter Cracker Manufacturing: Overall Design, Testing, and Implementation of All Facets of a Manufacturing Assembly Process." Montana State University has adopted a version of this module for junior-high-school students.

On and Off-Campus Internships. A pilot program that has showed particular promise in improving retention is Boise State University's efforts to provide lower-division students with significant work experiences, including on-campus research activities and off-campus internships. Begun in 2004-05 with seven students, all of whom the program retained, it grew in 2005-06 to include the placement of 13 first- and second-year students in industry internships and 20 in College of Engineering labs, which led to a retention rate of 97 percent. Although freshmen and sophomores are not the usual candidates for internships, this program showed that these students possess a wide range of skills attractive to employers and applicable in lab work. The high retention rate can be attributed to mentoring by faculty, upper-division students, and professionals; providing the students with good employment opportunities; and allowing them to envision themselves in their chosen profession

Humanitarian Engineering. Finally, the Colorado School of Mines has developed a minor in humanitarian engineering. So far, the proportion of women participating in humanitarian-engineering design projects exceeds the proportion of women in the general population of engineering students. Completed designs include an orphanage in Romania, a drip-irrigation system in Senegal, a water-and-sewage system in Honduras, and village lighting in Ecuador. As a result of the program, students sometimes change their career plans. For example, instead of working for a microchip company, one participant, Deborah K. Silva Ortiz, wants to use her electrical-engineering degree to work on power distribution for people in developing countries.

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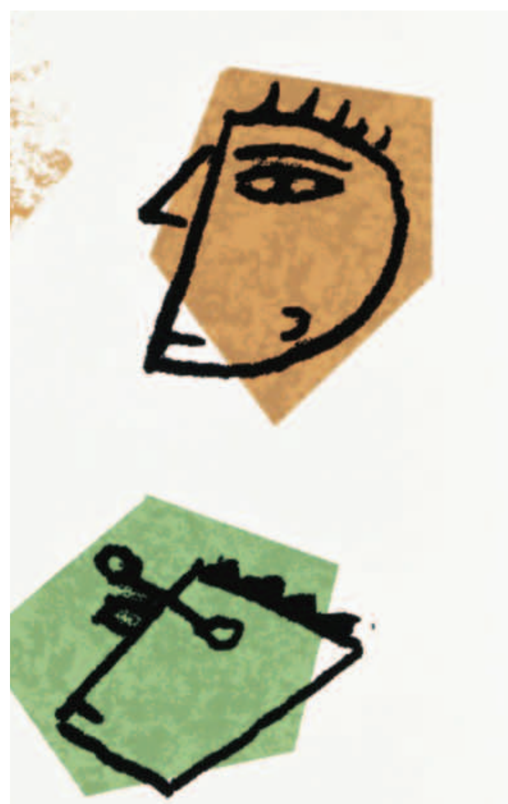
Collaboration Among Institutions

The emphasis on collaboration among institutions was explicitly built into the grant-making process. During its selection process, Hewlett asked representatives from the "semi-finalist" schools to a meeting, with the understanding that the foundation was prepared to fund all of their proposals but only if they used the meeting to generate additional ways to collaborate and to describe how they were going to do so in a set of revised proposals. This procedure had the immediate effect of moving the participants from a competitive to a collaborative posture.

Then the foundation held aside funds to support periodic committee meetings among participants from each school. Eliminating travel costs resulted in a very high degree of participation, while also serving to make explicit the expectation that some of the program outcomes should come from collaboration.

The commitment to sustain the project once grant support ceased also benefited from the power of collaboration. From the project's inception, development officers from each institution worked together on a "sustainability committee" to find ways to support their individual schools' efforts and the ESWI effort as a whole after the Hewlett funding ended. The work led those officers to collaborate on other development initiatives unrelated to ESWI. In effect, the ESWI program became a way for the development officers from the nine schools to form an informal development association.



Similarly, the decision to include assessment specialists from each school on an ESWI assessment committee, with the goal of bringing together data from all of the participating institutions, had significant ripple effects. Many of the specialists came from the schools of education, and their perspectives provided a welcome addition to the discussion. Most engineering faculty felt out of their element in the assessment area, and the expertise of their education colleagues resulted in a new-found appreciation for what this part of the institution could bring to the table. The collaborations not only among schools but also between education and engineering faculty are likely to have long-lasting positive effects on engineering education at these institutions.

The fact that the assessment work also provides a potential publication path for many of these specialists has been another important payoff. To date, more than 75 peer-reviewed papers and conference presentations have resulted from ESWI-supported activities. Most presentations have taken place at the annual meetings of the American Society of Engineering Education (ASEE) and the Frontiers in Education conferences, but others have been given at non-engineering venues, such as the meetings of the American Educational Research Association (AERA) and the Western States Communication Association. Publications have appeared in the ASEE *Journal of Engineering Education* and *Communication Education*, a journal of the National Communication Association. Many of these papers and presentations have resulted from collaboration between education and engineering faculty. The alignment of the ESWI sustainability and assessment committee objectives with the "day jobs" of the institutions' development and assessment specialists has been an important element in project's success thus far.

Within the ESWI project, fertilization of ideas among participants typically takes place in three venues:

Annual Meetings. A two-day annual meeting is held at one of the participating institutions, usually immediately after the annual American Association for Engineering Education (ASEE) meeting in June. The foundation funds the travel costs of participation in the meetings, which not only include engineering faculty but also other participants from the project's grantees (development officers, assessment specialists, education faculty, and deans), as well as guest speakers. At the meeting, each school gives a very brief presentation on activities during the previous year, followed by a detailed examination of lessons learned and specific areas where advice and help would be appreciated. At the conclusion of all the presentations, several hours are set aside for group discussion, suggestions, and offers of help in the form of collaboration, sharing of databases, evaluation instruments, and curricular materials.

Committee Meetings and Activities. Shortly after the ESWI grants were awarded, five committees were set up with at least one member from each of the nine institutions on each committee. As with the annual meetings, Hewlett set funding aside to support travel and other costs, such as developing assessment databases and promotional materials. Most of the committees meet at least once a year, in addition to the time allowed at the annual meeting, and many committees use video-conferencing tools for additional collaboration. Some communications cross committee lines: Course changes, new courses, curriculum modules, and any other curriculum innovations are shared by the curriculum committee via the annual meetings and the ESWI Web site.

Institutions carry out local assessment more specific to their programs, but assessment data from the whole group are important in determining best practices that are more generalizable. The assessment committee developed a comprehensive assessment plan, which includes objectives and measures that cut across the nine institutions. The recruitment and retention committee worked to develop an inter-institutional "Recruitment and Retention Best Practices" list from a common assessment form sent to all schools. The faculty-development committee created and administered a survey to elicit both faculty members' and administrators' perceptions about how their schools value and reward excellence in teaching and the scholarship of teaching and learning. The committee now is analyzing more than 180 responses from faculty and more than 50 from administrators.

A Sustainability Committee. This panel is working on creating a non-profit 501(c)(3) consortium involving the nine original schools, and possibly others, to move the various ESWI activities to sustainable institutionalized funding or other support. The sustainability committee has also used part of its original committee funding to provide small grants to the institutions through the Sustainability Mini-Grant Program.

Institution-to-Institution Exchanges. The annual and committee meetings often lead to a desire for individual exchanges among participants of two or more institutions. For example, Northern Arizona University and Montana State University have adopted some robotics activities from the University of Nevada, Reno, and Reno is adopting manufacturing-activity exercises from Boise State. Supplemental instructional courses at Reno have also been a helpful model for planned supplemental instruction courses at Montana State. Northern Arizona is using Oregon State's freshman retention survey, and Oregon State faculty reviewed proposals for Northern Arizona projects.

Collaboration is enhanced by the ESWI Web site (http://eswi.hewlett.org), which has links to the programs at each institution. Using a password, participants can read e-mail correspondence within and between committee members, view presentations from the annual meetings, and access useful databases and assessment tools, all of which serve to keep participants up to date while fostering further collaboration.

Lessons Learned Beyond Engineering

What are the lessons that *Change* readers can take away from our experience? The most generalizable lessons come from our experiences with furthering collaboration across disciplines and among institutions.

The capacity to serve as models for other institutions was crucial from the beginning, and this also applies to consortia or partnerships among schools or among schools, government, and industry. But colleges and universities are apt to ignore innovations adopted at other institutions, even though if successful strategies were copied more widely, the gains would be enormous. To increase such "knowledge capital," the benefits to all participants must significantly exceed the costs required in time, effort, and money.

The engineering-education project had the advantage of Hewlett funding and encouragement to institutions to work together. But what are some low-cost approaches that can facilitate other such collaborations?

- First, administrators need to provide faculty with examples of collaborations that are already working, either from within the institution or from similar colleges and universities.
- They also must lower or eliminate barriers to collaboration by setting aside infrastructure funds (money for travel, meeting facilities, facilitators, documentation) to support such efforts. It is important too for administrators to make clear to all potential faculty, students, and staff participants that collaboration is an *explicit* part of the criteria for initial and continued funding and that periodic written *evidence* of such collaboration is required. This may mean doing fewer projects than might otherwise be feasible. In the ESWI project, nine institutions were supported instead of 10 in order to sequester funds for i ncreased collaboration.
- Furthermore, collaboration must be an explicit part of a faculty member's professional responsibilities, not an add-on. Those who take on new collaborative responsibilities should either be allowed to eliminate a portion of their existing responsibilities or be allowed to bank the extra time for tradeoff later. If neither of these approaches is possible, faculty should be given extra compensation.
- It is a good idea for participating institutions and departments to assign portions, however small, of the salaries of as many staff and (especially) faculty as possible to the grant. One of the ESWI institutions has almost 30 staff and faculty assigned in such a way. Doing so reminds everyone of his or her role in the effort. Some of the simplest approaches can be the most cost effective. A dean at one of our ESWI schools set up a $1,000 account at the faculty club and told everyone participating in the program to take at least one other person from inside or outside the group to lunch every month to talk about the project. He asked them to report on who went to lunch and when, but that's all. When two faculty members went to lunch, they would often see other sets of participants doing the same thing; on occasion this led to four or more of them sitting together for a discussion.
- It is also important for administrators to make it clear that project funding is for a fixed period of time and that the participants need to start thinking early about gathering ideas and data that will make the case for follow-on funding from other sources.
- A key to making a case for follow-on funding is effective assessment. While allowing for the uniqueness of each department's or institution's efforts, it is important that all participants follow a basic reporting and assessment plan that identifies inputs, activities, projected outputs, and measurable outcomes.
- It is important to assign a portion of someone's time to facilitate and monitor collaborative efforts across departments or schools. One of us, Richard Reis, devotes about 20 percent of his time to this role, supported by a separate allocation from the Hewlett Foundation.

Conclusion

The engineering-education project is a bit more than half way through its five-year funding cycle. To date, formal assessments have come primarily from the annual reports produced by each institution as a requirement for the annual renewal of funding. However, the project's assessment committee, under the direction of the University of Nevada, Reno, is collecting and analyzing common data from all the schools for use in an inter-institutional evaluation. The intent is to compare and contrast program design, methodologies, operating assumptions, conceptual frameworks, and approaches and strategies for problem-solving to help determine best practices. The results of this work will be used by the ESWI sustainability committee to make the case for continuation of projects at existing schools and extension of support for the successful elements of projects to additional institutions.

Reform in engineering education is happening slowly but surely. For the ESWI schools, collaboration across institutions has been the key to maximizing the effects of change and the investment of foundation funds. In this case, the whole is, indeed, greater than the sum of its parts.

Resources

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