A K-12/University Partnership: Creating Tomorrow’s Engineers*

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Abstract

Supported by the National Science Foundation, the GK-12 Fellows program at the University of Colorado at Boulder explores innovative ways for engineering graduate students to use engineering as the vehicle to provide K-12 classroom instruction and hands-on experiences that integrate physical sciences, mathematics, engineering and technology. Engineering “Fellows” fill a crucial gap in the two-way exchange of content and pedagogy between the College of Engineering and Applied Science and the K-12 community of learners. The active presence of real world, engineering role models in K-12 classrooms improves the quality of math and science content, and introduces engineering to teachers and young students as a potential career path. Working through the University’s graduate program legitimizes K-12 outreach as a valid, and satisfying, academic endeavor for graduate students.

I. Introduction

Despite the pervasive influence of engineering and technology in everyday life, the number of undergraduate degrees in engineering has dropped nationally since the mid-1980s. Moreover, the proportion of engineering degrees earned by women and minority students continues to be significantly less than their representation in the general population. The primary goal of the program described herein, initiated in fall 1999, is to explore innovative uses for engineering graduate students to serve public K-12 classrooms, with an underlying goal of motivating more students to pursue a future in the engineering profession.

The program delivers hands-on, project-based educational curricula and activities to precollege students and teachers, thus providing an opportunity for K-12 students and teachers to experience the wonders and opportunities of education and careers in engineering and technology. In addition, the GK-12 program models a meaningful partnership with K-12 teachers and schools that could be adapted for use by other engineering colleges.

The National Science Foundation (NSF)** launched the Graduate Teaching Fellows in K-12 Education (GK-12) program in 1999 to provide fellowships to qualified science, mathematics, engineering and technology (STEM) graduate students to serve directly in K-12 classrooms as science and mathematics resources (see Figure 1). Each fellowship provides a stipend, tuition, fees and benefits. In return, Fellows work with specific teachers in K-12 classrooms about 10 hours weekly, as well as up to 10 additional hours per week outside the classroom on such tasks as preparing standards-based curriculum, planning activities with teachers, and participating in other in-house outreach activities.

By 1999, the Integrated Teaching and Learning (ITL) Program at the University of Colorado at Boulder had already established a K-12 engineering outreach program. The addition of K-12 in-class support by graduate students rounds out the engineering outreach program, which includes summer resident camps for under-represented high school students of color; weeklong hands-on engineering summer classes for elementary and middle school students; and weeklong engineering professional development workshops for K-12 teachers.

The GK-12 program is of significant benefit for the Fellows as well. In addition to traditional coursework and research, Fellows receive training and coaching in teaching, mentoring and communication skills. Their strong interests in teaching and outreach are nurtured within the context of their engineering degree programs.

II. Program Objectives

The ITL Program is a College-wide endeavor that integrates engineering theory with practice in a hands-on, team-based


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learning environment. At the heart of the GK-12 program is the ITL Program's commitment to share proven and powerful learning by doing techniques with students of all ages. We believe that hands-on, active learning enlivens the learning process for all students so they more fully engage in the excitement and satisfaction of gaining competencies in science, math and technology. Towards that end, we are committed to furthering our partnership with the Boulder Valley School District (BVSD). This partnership extends the success of our hands-on undergraduate engineering program by providing a unique graduate student learning and mentoring experience that also impacts the K-12 community.

The ITL's GK-12 program goals are to:

- Use engineering as a vehicle to integrate applied technology, physical science and mathematics instruction in K-12 classrooms.
- Promote the Fellows as effective engineering role models for K-12 students (see Figure 2).
- Develop the Fellows' teaching skills in engineering-related topics.
- Develop the Fellows' communication skills so that they teach students at age-appropriate levels and interact with teachers in a sensitive, respectful manner.
- Create opportunities for GK-12 Fellows and K-12 teachers to learn from each other.
- Enhance K-12 teachers' content knowledge by integrating physical sciences and math in experimental engineering modules developed by the Fellows.
- Enhance teachers' knowledge and understanding of engineering, thus helping them recognize possibilities for applying science and mathematics in everyday, real-world engineering and technology contexts.
- Connect elementary and secondary learning to the habits and skills required for further study in SMET disciplines.
- Increase the pool of qualified future engineering students.
- Graduate 20+ advanced engineering students with rich K-12 outreach experiences to take to their future careers, promoting ongoing engagement of the engineering community with K-12 education.

III. PROGRAM ADMINISTRATION

The first three authors serve as co-principal investigators for the NSF GK-12 grant. Sullivan and L. Carlson are co-directors of the ITL Program, and deGrazia is director of outreach. Together, they lead the GK-12 program. In addition, six faculty mentors, representing five of the six engineering departments in the College, provide one-on-one supervision of individual graduate Fellows and serve as content resources. Mentors receive modest summer support from the grant, and legitimize K-12 outreach throughout the College as a valid academic activity.

IV. FELLOW SELECTION

The recruitment and selection of Fellows reflects the interdisciplinary nature of the program. Much to our satisfaction, top-notch graduate students from every discipline in the College applied to the program in response to recruitment flyers and posters distributed throughout the College, and/or contacts with College faculty who value K-12 outreach. More than 30 students submitted applications in each of Years 1 and 2. A résumé, brief academic history and a personal statement comprised the application. Ten students from five departments were selected in both Years 1 and 2. While only about one in five CU engineering graduate students are female, the program attracted enough women applicants to equally gender-balance our Fellows. Successful selection criteria included a strong academic record, a commitment to the program as evidenced by the personal statement and experience working with youth. By its very nature—impacting K-12 SMET education so it appeals to a diverse group of learning styles—the fellowship opportunity attracts women and members of underrepresented groups who are often lost in the engineering pipeline. As noted by Tobias, "Certain students, among them women and most likely our second tier, would respond better to science if more cooperative and interactive modes of learning were part of the pedagogy."
and if scientific knowledge were more closely and explicitly linked to societal issues."

During the course of the three-year program, approximately 20 graduate and eight undergraduate students were projected to participate. This assumed that half of the Fellows would serve a two-year stint. Disappointingly, only one of the 10 Year 1 Fellows continued on to the second year. This higher-than-expected turnover was attributed to numerous factors, including earlier-than-anticipated graduation, unexpected leave of absence from school and offers for prestigious internships. However, from Year 2 to 3, more than half the Fellows continued, in line with our original expectations, improving the program's year-to-year continuity.

V. FELLOW TRAINING

An important aspect of the GK-12 program is the preparation of the Fellows to honor their commitments to the public school district concurrent with pursuit of their own advanced studies. To ensure the Fellows would be prepared to succeed in the K-12 classroom environment, we made arrangements for the BVSD, the CU School of Education and the CU Graduate Teacher Program to provide multi-faceted training. However, our original hopes proved largely inappropriate, since training by these groups was too specific to other audiences. While we found that the BVSD new teacher induction program was not a match for our program, the classroom management seminars presented were quite valued by the Fellows. The CU Graduate Teacher Program, although structured for university-level teaching, does provide useful workshops, such as one on Kolb Learning Styles. To supplement this training, we have found it worthwhile for retired and current K-12 teachers to lead workshops for the Fellows, discussing how to design age-appropriate activities as well as classroom management techniques and strategies.

We originally envisioned a six-week training program prior to the Fellows entering the K-12 classrooms, but found that to be unrealistic. Fellows and teachers alike were anxious for the Fellows to become directly engaged with students as "Engineers-in-Residence," and timing was not suitable for advanced training because the K-12 academic year began before the grant was received and Fellows were recruited. In subsequent years, however, we have found that training in the two weeks prior to the start of the fall semester, bolstered by an occasional workshop during the school year, provides adequate training.

VI. EXPLORING EFFECTIVE USES FOR ENGINEERING FELLOWS IN K-12 SETTINGS

The passion for K-12 outreach—and the supportive environment to bridge the gap between CU engineering and the pre-college community—already existed within the IITL Program team. The Fellows enter an active K-12 outreach program in which pre-college educators are respected and the challenges faced by the Fellows in the classroom are valued and, to some extent, understood. The common motivation for K-12 outreach, as determined during the Fellow selection process, provides a natural bond that transcends their diversity of research interests. Formal team-building activities, the training embedded in the program and regular team meetings promote a sense of support and camaraderie among Fellows.

A. Fellows Roles

Fellows, who each hold a half-time graduate appointment, work 15-20 hours each week in and out of classroom settings. Responsibilities include developing curricula and serving as in-class content resources to teachers and students. The greatest impact is achieved when the Fellows interface directly with the students; therefore, we request of classroom teachers that the Fellows provide about 10 hours of their total weekly time commitment in direct student contact. Outside of classroom time, Fellows develop, test and document curriculum materials under the guidance of their faculty mentor and classroom teacher(s).

During summers, Fellows develop and co-instruct K-12 teacher workshops and children's camps and classes side-by-side with teachers and CU engineering faculty. In addition, continuing Fellows help train new Fellows in advance of the new academic year.

An important objective addressed throughout our program is a focus on engineering. We strive to have Fellows perceived and admired as engineers, not scientists, furthering the belief that

Scientists investigate what is; they discover new knowledge by peering into the unknown.

Engineers create what has not been; they make things that have never existed before.

B. Applied Technology

All BVSD middle schools have Applied Technology Centers that offer elective, hands-on modules in technology-based topics. Applied technology settings are good matches for engineering students, as staffing of these centers can be a significant challenge to the school district. Likewise, Fellows can assist in high school-level design, engineering and technology labs. These labs support students in grades 9-12 as they explore more than 40 hands-on, integrated projects in areas such as advanced robotics, electronics, computer and network troubleshooting, digital image processing, geographic information systems, and medical sciences technology.

In Year 1, three Fellows served in middle school and two Fellows served in high school Applied Technology Centers, while in Year 2, that number was reduced to two Fellows assisting in middle school Applied Technology Centers, to free up Fellows for our shift to an elementary-level emphasis, deemed of greater need and impact.

C. Physical Science and Mathematics

Because physical science and mathematics are gateways to engineering, some Fellows were assigned to middle school physical science classes, and high school physical science, physics, and chemistry classes. Mathematics classes also provide suitable settings to introduce engineering activities that cement theoretical math concepts. For example, one Fellow successfully developed multiple hands-on curricular components for an 8th grade geometry class. Another Fellow developed a traveling, hands-on demonstration emphasizing the importance of math to a future in engineering and technology. Her "Everyone Does Math" talk emphasizes real-life use of math and how it affects everyone's lives. Delivered throughout the district to 20+ elementary through high school classrooms in Year 1 and continuing in Year 2, the interactive presentation is a hit with students.
D. Elementary Level

We erroneously anticipated that the Fellows would have the least impact at the elementary level. To our surprise, perhaps our greatest impact on teachers and children has been at the elementary level, where our pilot elementary school renamed their science lab the “Engineering Lab” and committed that every class—kindergarten through 5th grade—participates weekly in activities that teach fundamental engineering concepts. In Year 1, two Fellows co-taught at one elementary school. After the success of Year 1, we expanded to a total of six Fellows at four elementary schools.

E. Curriculum Development

After two years of the program, the Fellows have created and documented a robust supply of K-12 curricular materials. For the elementary level, two- to four-week blocks of curricula have been developed for the topics of laws of motion, energy, electricity and magnetism, and environmental science. Middle school students have explored such topics as the ideal gas law and phase behavior, structures, and environmental science. Innovative high school lessons include Lifebeats and Life Preservers, Electrically of a Dirty Cup, and Dead Christmas Lights and Your Car Battery, all of which use engineering as a vehicle to integrate age-appropriate math and science fundamentals.

F. Summer Outreach

In addition to being a time for Fellows to regroup, develop curriculum, emphasize training and prepare for the upcoming semester, summer is an essential component of the GK-12 program. Because their involvement is critical to the ITL Program’s in-house summer K-12 outreach offerings, Fellows are expected to contribute half time during the summer. The ITL Program has engaged in outreach to the K-12 community since 1997. In 1998, the Colorado Commission on Higher Education (CCHE) designated the ITL Program as a “Program of Excellence” and funded a five-year, “K-16 Integrated Engineering Outreach” program, earmarked primarily for engineering outreach to the K-12 community. The development of interactive, standards-based science, mathematics, and technology engineering curriculum and activities is central to the weeklong summer classes for K-12 children and weeklong summer professional development workshops for K-12 teachers. In addition, the on-campus “Success Institute,” an intensive multi-day, hands-on introduction to engineering for high school students from under-represented cultural groups, is conducted each summer. The Fellows design and document curricular activities, mentor student teams, and guide the hands-on activities, working directly with young students and their parents.

These many and varied year-round opportunities provide learning experiences for Fellows that result in improved teaching skills, an appreciation for K-12 challenges, enhanced communication skills on many levels, and an awareness that K-12 interaction is a lifelong endeavor.

VIII. Lessons Learned

Continuous program improvement has been realized by a willingness to adjust and adapt as important lessons are learned. One early critical lesson was realizing the importance of teachers clearly understanding program goals, such as NSF’s requirement and our desire that the Fellows have extensive and direct student contact so that the younger students gain an awareness of engineering as an exciting and viable profession. When Fellows serve as classroom instructors, they are viewed by students as engineering role models and as real people. We found that most Fellows thrive when they independently develop and present new curricular units, not contribute...
How much has your students' content knowledge of science, engineering, math or technology increased?

Figure 3. Year 2 K-12 teacher responses to a survey question regarding content knowledge. Average response = 4.2/5.0.

How much has your students' understanding of what engineers do changed or increased?

Figure 4. Year 2 K-12 teacher responses to a survey question regarding students' understanding of what engineers do. Average response = 4.3/5.0.

...as a background technician or teacher's aide to build new experiments.

We also learned that, logistically, sharing one fellow between two schools is ineffective, while team teaching—one Fellow at one school—works well. It helped to have one male and one female in the co-teaching team, to serve as role models for each gender. Also, two graduate students bring an emphasis in different engineering disciplines, adding to the depth of material presented.
They also support and encourage each other in unfamiliar situations.

Matched personalities (human chemistry?) and mutual respect between teachers and Fellows are musts for success. Careful placement of Fellows with appropriate teachers results in an intellectual partnership that yields significant impacts.

We modified our original plan in Year 2 by assigning faculty mentors responsibility for success at one school, supervising the one or two Fellows at that school, instead of pairing mentors with Fellows from related academic disciplines, regardless of the Fellows’ K-12 school assignment. With this modification, mentors are more apt to visit their one school, observe the Fellows in the classroom setting, and relate with and commit to its personnel.

Originally, we selected one elementary school, three middle schools with both physical science and applied technology programs, and three high schools, one a vocational alternative. In Year 2, we changed focus to serve four elementary schools, two middle schools and one high school. Our change in the mix of schools demonstrates our increased emphasis at the elementary school level. We found that we had significant impact at the elementary level, because many of those teachers lack a strong physical science and math background and welcomed the infusion of such content knowledge. They were also highly receptive to the in-class partnership. Candid Fellow exit survey feedback indicated that the program provided little enrichment in two of the three middle schools where the teachers were well organized with prepared lessons and excellent science content knowledge. In these cases, the teachers used the Fellows more as classroom assistants than as co-instructors. Also in the middle schools, the open-structure format of the Applied Technology Center labs was not conducive to program impact. The movement of students through the lab in six-week cycles did not enable Fellows to deliver meaningful curriculum—most of the time was spent learning equipment at different stations with little or no time left to apply technology. The underlying reason we reduced the program’s presence at the high school level was a disappointment to us. We find that by high school it is too late in most students’ education to make a career path impact. Also, most of the classes are so structured and packed with a set curriculum and content that there is little flexibility to accommodate our program.

In all cases, after Year 1, we felt compelled to consider a lingering concern: Are we “saving the saved”? We knew we were making an impact, but were we touching the students who otherwise would not have the opportunity to pursue or even consider a career in engineering? To address this concern, the Year 2 program added one elementary and one middle school that serve the lowest social and economic status students in the region, and have significantly lower test scores than neighboring schools. In addition, we expanded the Fellows’ summer outreach responsibilities to include contributing to university programs for high school students of color.

Additional Year 2 improvements, based on first-year lessons learned, included conducting recruitment earlier, requiring summer commitment up front, scheduling a program planning session with all participating teachers prior to the onset of the fall K-12 semester, and engaging seasoned Fellows in the orientation and training of the new cohort of Fellows.

IX. SIGNIFICANT SUCCESSES

Surprisingly, our most significant early success was at the elementary level. The Fellows at this level developed a strong partnership with the teachers, who trusted them to teach their students in
the Engineering Lab for a portion of each week. And, the children gained a new perspective on who engineers are and what they do, going so far as to think that engineers are "cool."

Program recognition has been a significant success. We were contacted by a number of other district schools inquiring about the possibility of having Fellows at their schools. Graduate students in the College of Engineering and Applied Science quickly became aware of the program. In fact, one academically outstanding civil engineering graduate student chose to apply to CU-Boulder specifically because of the GK-12 program.

The availability of Fellows greatly expanded the existing ITL Program's K-12 engineering outreach program by adding hands-on outreach in public schools throughout the academic year. With the contribution by Fellows, more K-12 students participate in pre-engineering hands-on activities, more teachers' professional development workshops are conducted, and participation in summer pre-engineering resident workshops for high school students of color has more than tripled. In short, the GK-12 program has enabled a comprehensive K-12 engineering outreach program that far exceeds our initial expectations.

X. Conclusion

The GK-12 fellowships attract a diverse group of graduate students interested in the impacts of engineering and technology on society. It is our hope that ambitious outreach activities like this will stimulate qualified K-12 students to consider careers in engineering and technology. We believe that engineering belongs in the K-12 classroom, not as science, but as its own discipline that provides a career path for students who previously had no idea of what it means to create things for the benefit of society.

We conclude that the GK-12 Fellows Program is having a positive impact on K-12 children, teachers and schools. We will continue to develop and refine the program to have the greatest possible impact on the largest number of students. And, we intend to explore ways to sustain this program after the NSF grant expires, as well as export the program's approach to other U.S. engineering colleges.

We believe that intimately engaging with the K-12 sector is vital to our engineering education mission. The potential impact that our nation's 300+ engineering colleges could have on the K-12 sector is staggering, and the value to society of enriching the engineering culture with people from all walks of life and societal sectors is immeasurable.

REFERENCES


5. Quote from Joe Bordogna, Director for Engineering, National Science Foundation, 1996.
