ENGINEERING IN THE K-12 CLASSROOM: A PARTNERSHIP THAT WORKS

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Abstract *¾ Recently funded by the National Science Foundation as an engineering "GK-12" program, the GK-12 Fellows program at the University of Colorado at Boulder explores innovative ways for engineering graduate students to provide in-class public K-12 instruction in engineering, technology and physical sciences. 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. Working through the University's graduate program legitimizes K-12 outreach as a valid, and satisfying, academic endeavor for graduate students*

Index Terms ¾ engineering outreach, K-12 outreach, NSF GK-12 program, outreach.

INTRODUCTION

Despite the pervasive influence of engineering and technology in everyday life, the number of undergraduate degrees in engineering has dropped nationally during the past several years. Moreover, the proportion of engineering degrees earned by women and ethnic minority students is 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 choose a future in the engineering profession.

The program delivers hands-on, project-based educational curricula and activities to pre-collegiate students and teachers, while 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 to providing resources to K-12 teachers and students, this GK-12 program models a meaningful partnership with K-12 teachers and schools, one that could be adapted for use by other engineering colleges.

Last year, the National Science Foundation (NSF) introduced the *Graduate Teaching Fellows in K-12 Education (GK-12)* program. The program provides fellowships to qualified science, mathematics, engineering and technology graduate students to serve directly in K-12 classrooms as science and mathematics resources (see Figure 1). The graduate fellowships provide support for the students' research and their participation in K-12 classrooms a minimum of 10 hours weekly.

The Integrated Teaching and Learning (ITL) Program at the University of Colorado at Boulder was funded in 1999, making our dream for *Creating an Integrated Engineering and Technology Continuum* become a reality. The K-12 in-class support by graduate students rounds out the extensive ITL engineering outreach program that includes summer resident camps for under-represented minority high school students; 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 degree programs.

FIGURE 1.
FELLOWS BRING STRONG ENGINEERING, MATHEMATICS AND SCIENCE CONTENT DEPTH INTO PUBLIC K-12 CLASSROOMS.

PROGRAM OBJECTIVES

The emphasis of the ITL Program in the College of Engineering and Applied Science is on integrating engineering theory with practice in a hands-on, team-based 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 of all students so they more fully engage in the excitement and satisfaction of gaining competency in

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science, math, and technology [1]. Towards that end, we are committed to furthering our partnership with the Boulder Valley School District (BVSD). This partnership will extend 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 of learners.

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

- Create opportunities for GK-12 Fellows and K-12 teachers to learn from each other
- Create the conditions for successful curriculum development collaboration between the Fellows and K-12 teachers
- Assist in applied technology, science and mathematics instruction in K-12 classrooms
- Exploit the Fellows as effective engineering role models for K-12 students (see Figure 2)

FIGURE 2.
FELLOWS SERVE AS REAL-WORLD ROLE MODELS FOR YOUNG STUDENTS, SHARING THEIR ENTHUSIASM FOR ENGINEERING AND TECHNOLOGY.

- Integrate the use of project-based, hands-on learning with the K-12 math, physical science, and technology curricula
- Develop the Fellows' teaching skills through an exchange of Science, Math, Engineering and Technology (SMET) content and teaching pedagogy between Fellows and teachers
- Develop the Fellows' communication skills so they teach students at age-appropriate levels and interact with teachers in a sensitive, respectful manner
- Enhance K-12 teacher SMET content knowledge by integrating physical sciences and math in experimental modules developed by the Fellows
- Enhance teachers' content knowledge and understanding of engineering, thus helping them recognize possibilities for applying science and mathematics in 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 that they will take forward to their future careers, promoting engagement of the engineering community with the K-12 educational system.

PROGRAM ADMINISTRATION

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

FELLOW SELECTION

The recruitment and selection of Fellows demonstrates 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 known to value K-12 outreach. More than 30 students submitted applications. A résumé, short academic history, and a personal statement comprised the application. Ten students from five (of six engineering) departments were selected; we were fortunate to be able to gender-balance. Selection criteria included a strong academic record, a commitment to the program as evidenced by the personal statement, and experience working with children. To our delight, many successful applicants had extensive prior experience working with children to promote science literacy.

During the course of the three-year program, approximately 20 graduate and eight undergraduate students are expected to participate. Through its emphasis on impacting the nature of science education, the fellowship attracts women and other members of underrepresented groups who are often lost in the science and engineering pipeline. As noted by Tobias [2],

"Certain students, among them women and most likely our second tiers, 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."*

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 advanced studies. To ensure the Fellows were prepared to succeed in the K-12 classroom environment, the BVSD, the CU School of Education and the CU Graduate Teacher Program provided multi-faceted training.

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 to get the Fellows directly engaged with students as "Engineers-in-Residence," and timing was not suitable for advanced training because the K-12 academic year had already begun before the grant was received and Fellows were recruited. In future years, however, more extensive training will occur in the two weeks prior to the start of the fall semester.

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 ITL Program team. The Fellows entered 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, provided a natural bond that transcended their diversity of research interests. Formal team-building activities, the training embedded in the program, and regular team meetings promoted a sense of support and camaraderie among Fellows.

Fellows' Roles

Fellows were assigned to work a minimum of 10 hours each week with specific teachers in classroom settings. Responsibilities included developing curricula and serving as in-class content resources to teachers and students. Ultimately, we selected one elementary school, three middle schools with both physical science and applied technology programs, and three high schools, one a vocational alternative. Outside of classroom time, Fellows develop and pilot curriculum materials under the guidance of the faculty mentors and their classroom teachers.

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 during the summer.

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 a 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…[3]*

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 assist in the new high school-level "daVinci" design, engineering and technology labs. These labs support students in grades 9-12 to 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.

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 (see Figure 3). Mathematics classes also provide suitable situations to introduce engineering activities that cement the theoretical math concepts being learned. One Fellow successfully developed multiple hands-on components for an 8th grade geometry class.

FIGURE 3.
USING A HANDS-ON EXPERIMENT, A HIGH SCHOOL PHYSICS STUDENT EXPERIENCES THE PRINCIPLES OF ANGULAR MOMENTUM AS THE IN-CLASS INSTRUCTOR FELLOW LOOKS ON.

One Fellow developed a traveling, hands-on demonstration emphasizing the importance of math to a future in engineering and technology. Her "Everyone Does Engineering," emphasizes real-life engineering and how it affects everyone's lives. Delivered throughout the district to 20+ elementary through high school classrooms, the interactive presentations were a hit with students.

Elementary Level

At the elementary level, it was anticipated that the Fellows would have minimal impact. We were soon proved wrong! Perhaps our greatest impact on teachers and children in the

first year 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 engineering activities that teach fundamental concepts.

Summer Outreach

Another important role for Fellows is participation in the summer engineering outreach program. 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. Each Fellow is expected to participate in multiple ways in the summer and their involvement is critical to the ITL Program's summer K-12 outreach offerings.

The ITL Program has engaged in outreach to the K-12 community since its inception [4]. 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 exclusively 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 this program. These materials are delivered in weeklong summer classes for K-12 children and weeklong summer professional development workshops for K-12 teachers.

Examples of the classes and workshops are: *The Sounds of Music* (physics of music), *How* Do *Things Work*? (design and building of practical electromechanical devices), *Too Hot to Handle* (thermodynamics for middle school children), *Kinetics for Kids*, *Green by Design* and *Go with the Flow* (fluid mechanics for teens). Some Fellows create, prepare, test and document hands-on activities. Others serve as facilitators for the teacher's workshops, partnering with a faculty mentor. Still others work with a partner instructor to teach a children's engineering class.

In addition, the "Success Institute," an intensive two-day, hands-on introduction to engineering for local high school students from under-represented cultural groups, is conducted each summer. Fellows design and document curricular activities, mentor student teams, and guide the hands-on activities, working directly with the young inner city students and their parents.

The aim of these many and varied year-round opportunities is to 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 activity.

CONTINUOUS ASSESSMENT

To assist with the assessment and evaluation of the GK-12 Fellows program (among others), a CU School of Education graduate student spends 20 hours per week serving as our assessment specialist, assisting with the preparation, administration and analysis of assessment tools to gauge program success [5]. After the first semester, a full program review resulted in mid-year program corrections for Fellows, teachers and faculty.

Prior to the review, a K-12 teacher survey was conducted to solicit their input on program effectiveness and suggestions for improvement. Results indicated relationships between fellows and teachers were good and that they were learning from each other. Relationships between Fellows and students were maturing: the fellows were considered to be excellent role models, they related well with K-12 students, and were seen as "cool" and willing to help. Surprisingly, it was learned that student-Fellow contact was much higher at elementary level than at middle or high school. Teachers reported that Fellows were opening students' eyes to engineering, serving as excellent role models, helping make connections between math and science, providing a helpful second set-of-hands and serving as a conduit to CU engineering resources.

It was clear that teachers initially struggled to figure out how to effectively use the Fellows in their classroom. Identified program challenges included:

- Provide teachers with an better understanding of program goals
- Clarify expectations of teachers and Fellows
- Encourage teachers and Fellows to schedule a regular meeting time to collaborate and make plans.

A positive outcome of the teacher survey was learning that 100% of the teachers wanted to continue with the program, and would recommend the program to a peer.

LESSONS LEARNED

A number of formative and summative evaluation methods were used to assess the program components [5], leading to many *lessons learned*. One 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 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.

Most Fellows thrive when they independently develop *and present* new curricular units, not contribute *solely* as a background technician or teacher's aide to build new experiments, etc. We learned that, logistically, splitting Fellows between schools is ineffective, but team teaching at the elementary level works well.

Matched personalities (human chemistry!) and mutual respect between teachers and Fellows is a *must* for success. Therefore the placement of Fellows with appropriate teachers must be done carefully. When all works right, an intellectual partnership between teacher and Fellow yields significant impacts.

SIGNIFICANT SUCCESSES

Surprisingly, our most significant early success was at the elementary level. Our partner school renamed its Science Room the *Engineering Lab*. The Fellows at this school developed a strong partnership with the teachers who trusted them to teach their class 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."

A number of activities have been developed by Fellows to involve students in the creativity and fun of engineering. These include a *Science and Engineering Club for Girls*, developed in one middle school and ready to expand to a neighboring school.

Program recognition has been a significant success. We were contacted by a number of other schools in the district inquiring about the possibility of having Fellows at their schools. Graduate students in the College of Engineering quickly became aware of the program, and we received 17 applications for the remaining six Year 2 fellowship openings. In fact, one outstanding civil engineering graduate student chose to apply to CU in hopes of being included in the GK-12 program.

The availability of trained Fellows has increased the extent of hands-on outreach that can be offered from the ITL Program. Prior to the funding of GK-12 Fellows, academic year outreach was limited to tours of various engineering facilities. Now, with the assistance of the Fellows, teacher's professional development seminars are conducted, middle and high school students participate in hands-on activities, and teacher's Master's programs are presented.

PROGRAM CHANGES AND FUTURE THOUGHTS

A number of suggestions for the program's future will be implemented during the next two years, including:

- Identify two significant engineering projects to be developed and documented by each Fellow, one during the fall and one during the spring semester
- Ask Fellows to suggest high school engineering projects that give students a good exposure to engineering
- Research new hands-on demos and experiments
- Develop and present new experimental modules
- Perform limited equipment fabrication / maintenance
- Present "women in engineering" talks
- Regularly tutor in the high school tutoring center
- Consider using one Fellow dedicated to providing guidance solely on national competitions at all levels
- Consider having one "roving" Fellow to focus on math and science at all levels
- Require, up front, that Fellows commit to the program through the K-12 academic year and into the summer, which is longer than their University commitment
- Post curricular modules on the WWW.

After one year administering this GK-12 program, we have one lingering concern: *Are we "saving the saved?" We know we are making an impact, but are we touching the students who otherwise would not have the opportunity to pursue or even consider a career in engineering?* To that end, we have made Year 2 plans to expand the program to include an elementary and middle school that serve the lowest social and economic status students in the area, and that have significantly lower test scores than neighboring schools. We will place our "veteran" experienced Fellows in these schools.

Some additional changes made for Year 2 include conducting recruiting earlier, 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 orientations and training of the new cohort of Fellows.

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 topic that provides a career choice to students who previously had no idea of what it means to be an engineer.

Looking back upon the first year, we conclude that the GK-12 Fellows Program had a positive impact on the K-12 children, teachers and schools who were involved. We will continue to develop and refine the program for the next two years to have the greatest possible impact on the largest number of students. And we intend to explore ways to sustain this effective program after the grant expires, as well as export this program to other engineering schools throughout the US.

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