

## ENGINEERING OUTREACH: COMPONENTS OF A BEST MODEL FOR PROFESSIONAL TEACHER DEVELOPMENT

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**Abstract** – Can engineering successfully be taught to elementary school students? Though many people are quick to answer that children can learn about engineering, the subject can be challenging to integrate with elementary level curricula since few teachers possess training in engineering or engineering education, in specific. This paper will examine the results from two grants received by Tufts University: one National Science Foundation grant (NSF 9979593) and one grant sponsored by the Massachusetts Department of Education (MA 1698). Each grant focuses, to varying degrees of teacher involvement, on professional development to increase both engineering content knowledge and comfort level with engineering in the classroom. The National Science Foundation grant supports year-long placement of engineering graduate fellows with classroom teachers to infuse engineering into more traditional curricula; the grant from the Massachusetts Department of Education focuses on a week-long professional development summer course with follow-up meetings subsequent to initial intensive seminar. The strengths and weaknesses of both approaches will be discussed.

**Index Terms** – Engineering Outreach, K-12 Schools, Professional Development, Teacher Workshops

Tufts University's Center for Engineering Educational Outreach (CEEEO) is dedicated to furthering the educational engineering experience of students at all ability levels in grades K-12. As part of this effort, the CEEEO offers professional development workshops to teachers to foster understanding and application of engineering principles in order to further benefit critical thinking and problem solving in their classroom. As outreach activities, these professional development workshops require support from external funding opportunities as opposed to institutional funds, like student tuition. Two external funding sources involved in CEEEO efforts at various grade levels are the National Science Foundation (NSF) and the Massachusetts Department of Education (MDOE). Professional development sponsored by NSF has taken place under the auspices of the GK-12 program, while that from MDOE has occurred through Content Institutes. The CEEEO outreach program sponsored by the NSF serves grades 3 through 9, while the MDOE program serves grades 3 through 5; as a result, the focus of this paper will be the professional

development opportunities for teachers of grades 3 through 5, the overlapping grade levels.

### NSF GK-12 PROJECT

The Tufts University GK-12 project is a three-year project focused on pairing graduate-level engineering and computer science students with classroom teachers. The CEEEO had 6 graduate fellows in the first year of the project, and currently has 8 graduate fellows working with teachers. Graduate students apply to the program subsequent to their application to individual graduate program; top candidates are selected overall. The GK-12 fellowship takes the place of a traditional research assistant (RA) or teaching assistant (TA) position, with the same adjustments regarding graduate program length as RA or TA positions. The GK-12 fellowship in no way replaces independent graduate research in the fellow's field of study, coursework, or supplementary work with academic advisors. The fellows spend 20 hours a week on average working with the outreach project, with 16 hours (2 full days) per week spent in the classroom of their partner teachers. The project runs from June 1 to May 31 allowing consistent contact between graduate fellows and classroom teachers. During the summer months when school is not in session, fellows take part in activities to familiarize themselves with Massachusetts technology and engineering frameworks, learn general outreach activities, and to gain experience in working with teachers and students. Teachers were selected for participation both through classroom presence in a school district with a long-term history of collaboration with the CEEEO as well as self-selected through individual teacher initiative and contact with the CEEEO. All teachers received honoraria for yearlong participation in the outreach program.

### Graduate Fellow Classroom Role

Individual graduate fellows have varied roles in the classrooms that they serve, although each is there to act as a resource for students and teachers and to identify areas where engineering curricula can be integrated. Utilizing their backgrounds in engineering, fellows identify potential areas in more traditional classroom curricula where engineering content might be introduced or where teachers might integrate engineering design and problem solving to present, test, or reinforce content. Each Teacher-Fellow

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pairing has a unique character, depending on factors such as teacher and fellow personalities, comfort with traditional curricula, flexibility, and teaching style. For the most effective outreach, these factors must be carefully considered to ensure the development of dynamic relationships between fellow and teacher.

### **Fellow – Teacher Interaction**

Though interactions between graduate fellows and teachers are individualized, there are generalizations to draw from the program. These common threads help illustrate the impact of CEEO GK-12 outreach on those involved. Clearly, the most immediate beneficiaries of the outreach program are the teachers and elementary school children served by fellows. Graduate fellows work with students and teachers on engineering related projects that supplement more traditional math, science, or social studies content being taught. Though these engineering projects present important content—often contextualizing other lessons—without fellow presence, teachers are not likely to integrate them independently. Depending on the material and individual comfort levels, lessons are taught solely by the teacher, solely by the graduate fellow, or through joint effort.

For example, in fifth grade science, students might investigate the design of a weather station. Imbedded in the project, students must investigate how a thermometer works and the basic science principles involved, like thermal expansion. Based on their research, students might use trial and error to design and calibrate a thermometer allowing them to take reproducible measurements. Addition projects could involve research, design, and construction of barometers, anemometers, sundials, and weather vanes for the weather station. This traditional project involving weather stations can be supplemented to engage students in the engineering design process by building the components for the station themselves, from a variety of materials. In a similar way, a math class might reinforce the concept of multipliers by introducing students to the use of scale in engineering drawings and models. Students may design and build objects to scale or they may compose engineering drawings to scale from a model. In this way, a basic component of all engineering disciplines may help explain, reinforce, or contextualize more theoretical traditional mathematics. An example involving social studies relates to ancient civilizations, which were most commonly built along rivers. Students often learn as a part of traditional curricula that flooding was an important factor influencing farming and the subsequent development of societies, but rarely gain understanding of the wider implications of flooding on civilizations. Working with graduate fellows, teachers might devise a lesson plan utilizing stream tables and diatomaceous earth to investigate river patterns and the impact dams have on rivers. Students might have the opportunity to design a river system and investigate how dams can positively and negatively impact flood control.

These three scenarios serve as examples of student learning through engagement with the engineering design process. This process allows exploration of principles being presented in more traditional classes by presenting not only in hands-on experiences, but avenues for critical thinking and problem solving.

However, students are not the only beneficiaries of engineering outreach. Teachers learn the engineering design process as a result of fellow interaction; but more importantly, while developing classroom activities they are exposed to engineering content otherwise outside the purview of elementary level teachers. Prior to project or lesson implementation, teachers and fellows must jointly and fully develop lesson content and effective presentation. During the process, teachers often learn basic or upper-level engineering principles in order to support their presentation of material to students and to address any misconceptions regarding engineering content. For example, in the last scenario involving flooding, it was important to address the idea that dams caused flooding, as opposed to offering flood control, before the full project could take shapes in a classroom.

At the same time, graduate fellows also learn a great deal during the outreach program, though perhaps in a manner that is often overlooked. While many fellows enter the program as a result of interested in outreach and working with K-12 students, they typically do not possess training as educators or significant experience working in schools. The majority of the fellows have learned effective methods for instruction that can be translated between age groups. Although fellows are not seen as student teachers and do not possess comparable training, attending only a handful of educational seminars, fellows learn effective teaching strategies directly from students. Similarly, they learn effective, pedagogically valid approaches from partner teachers who often are sharing years of experience. Relevant to individual fellow's field of study, fellows become adept at breaking down complex concepts to present material in an understandable manner. Some fellows have commented that it has benefited their research and thesis writing by having to fully understand their own research in order that they can explain it to someone with little or no engineering background. This clarity of communication is, by far, the most transferable and valuable skill developed for fellows.

The NSF GK-12 project is a complex initiative. The above is one example of how the program functions in Grades 3 – 5, though many more examples exist. This brief overview of the program will be helpful in comparing this outreach project with the second project, funded through the Massachusetts Department of Education (MDOE).

### **MDOE CONTENT INSTITUTE**

The MDOE Content Institute was funded in 2000 and 2001 as a weeklong summer program for teachers of Massachusetts's students in grades 1 – 5. Teachers self-select to participate in the institute free of charge in order to investigate elementary engineering principles; there are no prerequisites for enrollment. The institute is structured firmly around the Massachusetts Science and Technology/Engineering Frameworks. The focus of each of the five days of the institute comes from standards that are included in these state-accepted frameworks. Teachers attend this workshop as opposed to others in order to learn how to implement relatively novel standards that often fall outside typical teacher training and to learn how they can most effectively offer framework material to their students

### Structure of the Institute

The institute is composed of three main instructional forums: lecture, discussion, and hands-on experiences. The seminar explores the educational standards required teachers; however, this institute innovatively presents fundamental physics and engineering concepts, as well as cutting-edge technology in engineering, which teachers may use to present framework content.

For example, one of the Grade 3 – 5 standards involves identifying and explaining the appropriate materials and tools to construct a model safely. In order to address this standard, teachers are exposed to material in two methods. First: an interactive lecture in forces, where teachers learn about tension, compression, shear, and moment. To demonstrate the different forces to the teachers, long, slender pieces of foam are utilized to make deformations under tension and compression discernable. The foam is also beneficial for explaining and exploring moment about a fixed point. Through this demonstration and hands-on learning, teachers begin to understand how different materials react under altered conditions. Discussion follows, in which common materials are listed and their “primary” strength identified as to whether they are stronger in tension or in compression.

The second method of examining materials is to construct a simple water filtration device. Teacher are provided with visibly contaminated water created by adding potting soil to tap water, 2-liter soda bottles, and a variety of filtering materials (including paper towels, cotton pads, cotton balls, coffee filters, cheesecloth, clumping cat litter, aquarium gravel, sand). Teachers are charged with building the fastest system that can deliver the clearest water. Time trials and comparison with various grades of clean water are used by the teachers in deciding how they wish to redesign their filtration systems. Typically, participants go through four iterations in the process to perfect their designs.

These are two approaches that are used to show teachers how material testing and selection can play an important part in the engineering design process. Through these two methods, teachers understand that there are

reasons and design trade-offs involved in selecting materials for specific purposes. This exercise also demonstrates that depending on the purpose that materials and designs will serve, there may be different selection criteria. Teachers gain this understanding through what can become an in-depth design problem; however, once in the classroom, they are often able to present less involved projects in order to relate similar content because of the depth of their understanding. A lesson regarding material selection is, in fact, multipurpose since it is also focused teacher attention on thinking nontraditionally to identify materials for any classroom project.

The basic unifying theme of the Content Institute is the engineering design process. In lectures, demonstrations, and projects, the focus is on the iterative engineering process. The core institute philosophy is that by teaching how the engineering design process works, teachers will be empowered to design their own lessons involving engineering. Without the development of a true understanding of the engineering design process, teachers would be forced to rote replication of the activities performed during the workshop.

### COMPARISON OF THE TWO APPROACHES

In the NSF project the main form of instruction is through casual conversation or direct communication between teacher and graduate fellow. Teachers work with graduate fellows for 16 hours per week for the entire school year. They collaborate on an ongoing basis on a variety of projects and approaches to teaching the material. The NSF Project is primarily based on involvement with one school district; therefore the majority of the fellows work with teachers from a single district. This allows for intra-teacher communication and support about how to approach effectively an engineering topic/challenge.

For the MDOE Content Institute, the instruction is intensive, direct, 40-hour instruction for self-selected teachers from many districts. In the Content Institute, the teachers are exposed to a limited amount of material common to many fields of engineering. In the example given, the teachers have a solid understanding of material selection, which is one of 8 main topics covered during the weeklong workshop, which include: Design Process, Engineering Graphics, Forces, Engineering Overview, Electricity, Lego Construction and Redesign. Teachers return to their individual schools where they often are the only champions of engineering, if not the only teacher attempting to integrate engineering in this way in the classroom. Year-long follow up does, however, support teachers' development of new or integrated curricula since teachers may consult with the institute staff for suggestions on effective project-specific implementation. There are also two formal group follow up sessions during the school year, at which teachers share classroom developments and receive clarification of content, as requested.

### Program Strengths

The NSF GK-12 initiative has several clear strengths, which include the provision for ongoing yearlong contact between teachers and fellows. A teacher-fellow bond develops, facilitating a trust-based relationship in which each becomes more willing to trust the other and try new approaches to offering new material to students. The duration of exposure to engineering graduate fellows also fosters the opportunity for teachers' exposure to a variety of engineering and engineering approaches to existing curricular material that may have greater relevance to individual teacher's needs and interests. Requiring graduate fellows to spend two full days each week with the classroom teacher increases student and teacher comfort utilizing the fellow as a resource with the full integration of engineering topics and projects without making these activities seem nonacademic. The increased levels of learning of all participants in the program are definitely a major strength of the program. A small stipend is provided for teachers who participate to help compensate for time committed to the project.

The MDOE Content Institute provides an intense weeklong workshop, in which participating teachers can take a "crash course" in engineering with limited long-term commitment. However, unlike the GK-12 outreach, the institute is linked directly to the state educational standards, so the relevance of application of the material is readily clear to teachers. Institute participants are exposed to a variety of lectures and hands-on demonstration that can be adapted for use in classrooms, or expanded upon to meet the needs of specific classroom/school/district. Institute teachers are tested on and leave the institute with a solid understanding of a basic pallet of fundamental engineering concepts with which to return to their classroom, unlike NSF program participants, who may learn about more varied and/or class-specific engineering content. Teachers from Massachusetts can receive Professional Development Points (Continuing Education Units [CEU's] for teachers outside Massachusetts) for their participation in the institute and for a classroom project if developed and implemented. Both programs result in the development of several projects or engineering-integrated units.

### Weaknesses of each Program

The GK-12 outreach project's major weakness is there is no provision for that "crash course" in engineering that the Content Institute provides. Often teachers must work quickly during the school year with little time for advance planning with the graduate fellow to create innovative curriculum for their students. Teachers have a limited amount of time during the school year already, and this program makes not insignificant demands of the time that is available. Also, the "mile wide and inch deep" approach valuing breadth over depth in engineering sometimes leaves

teachers with erroneous ideas or incomplete information about the engineering behind the experiment. Finding time in the graduate fellows' academic schedules when they are able to spend two full days in the classroom is a challenge as well. It is also important to pair personalities between teachers and fellows carefully since personality conflicts can deeply influence teachers to reject input from the fellow out of hand.

Similarly, MDOE Content Institutes also have weaknesses; most seriously is the limitation of institute material to the most basic premises of engineering: the design process. While it is important to consider the major engineering concepts that teachers should be comfortable with, the institute may not provide directly for specific teacher's content needs—particularly beyond a basic level in engineering. Due to the importance of serving multiple teachers in the same institute, the most applicable material must be covered to an acceptable degree of teacher understanding through the program. Also, as with most continuing education opportunities, institute teachers are returned to their classrooms without an immediate support network to construct and implement engineering projects. Predictably, this ensures a lack of quality control in the sense of assurances that a limited amount of engineering understanding is not being misused. The seminar approach relies on the teacher remembering all that was learned in the institute accurately and using a methodology that correctly expresses the engineering design process when instructing classes. There is a greater possibility that the teacher will return to the classroom without ever attempting to do an engineering design project since there is no in-class engineering presence to support the teacher. The institute method relies on building teachers enthusiasm for the new discipline and then hoping that they retain that enthusiasm as they return to the classroom.

### CONCLUSIONS

Clearly, current CEEO outreach endeavors present strengths and weaknesses – however, from these projects, a next generation of more effective guidelines shaping outreach projects may be crystallized. An approach to professional development of teachers impacting the integration of engineering with more traditional disciplines might be a hybrid of the two professional development approaches currently used by the CEEO at Tufts. The creation of one comprehensive workshop consisting in part of the intensive summer institute to give teachers background in engineering and the engineering design process, coupled with the continued support of the graduate engineering fellows. This approach would ensure that teachers gained a solid understanding of engineering, allowing them to explore the application of engineering and give exposure to the role of engineering within the state educational standards. Upon returning to the classroom, teachers would benefit greatly

from the support of a graduate engineering fellow. Teachers would have a classroom resource to brainstorm ideas with, to ask for technical information and support, to plan a coordinated activity for the classroom, and more. The teacher would not be left to identify how to integrate engineering into their curriculum and rely solely on the information learned during a weeklong summer workshop. During the course of each program, other factors influencing success have similarly been identified. Ideally, an opportunity during the summer should be reserved for graduate students and teachers to plan class curricula. This would alleviate some of the scheduling and organizational difficulties that are felt by teachers engaged with the project, as well as most effectively utilizing fellows, who are employed during the summer. Continued contact with other participants in program participants through electronic media (i.e. mailing lists, chat rooms, etc.) and with the instructor of the summer institute would serve as an additional resource. Classroom visits could be conducted by institute instructors to evaluate the delivery of the material

by the teacher, reception by the students, as well as addressing issues with content. Information from these visits could be used to reevaluate program methodology. Additionally, significant components of assessment would implicitly serve to strengthen any outreach program. These should not simply focus on student test performance change over time, but instead should assess attitudes and interests with respect to engineering for teachers, students, and fellows. Additionally the long-term impact on graduate students engagement in activities impacting education, particularly primary and secondary education should be assessed. Though these are several components that potentially embody an ideal professional development experience for this situation, clearly there is no single 'best' model for all outreach. Each situation provides unique obstacles and opportunities; the real challenge must become capitalizing on the opportunities while minimizing the obstacles to classroom impact.