AC 2009-1108: ENRICHMENT EXPERIENCES IN ENGINEERING (E3) FOR TEACHERS' SUMMER RESEARCH PROGRAM

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Enrichment Experiences in Engineering (E^3) for Teachers Summer Research Program

Abstract

For several years, the NSF-funded Enrichment Experiences in Engineering (E^3) program has developed partnerships with high schools across Texas, many of which are magnet programs that focus on science, technology, engineering, and mathematics (STEM) subjects, and all have student bodies that are primarily from underrepresented minority groups (average 88%), low income (average 77%), and first generation to college. The goal "to involve teachers in engineering research" has been accomplished by satisfying 3 objectives linked to the intended outcomes and impacts. The objectives are: 1) Provide contemporary engineering research experiences and enhance understanding of the nature of engineering; 2) Scaffold teacher development of authentic inquiry activities for the high school classroom; and 3) Improve public school teachers' knowledge about careers in engineering. Assessment of the program is integrated into its structure providing regular feedback which is used to continuously improve the program experience and impact. It should be noted that this is not a research project, and as such, there are neither research questions nor a research design. However, the E3 program has goals and anticipated outcomes, and has used qualitative questions to measure these outcomes.

The program has become more refined and impact is being felt through the state. Teachers are recruited from targeted schools, but the application is open to all teachers. Selection is rigorous and competition for available positions has intensified. Selected secondary (grade 8-12) science, technology, engineering, and math (STEM) teachers work in teams of 2 with engineering faculty in his/her laboratory during a 4-week summer residential experience. Working in ground-breaking research, the teachers have the opportunity to participate in experiments that they can integrate into their science/mathematics curriculum. Teacher teams apply in-depth education theory and learning experiences to better prepare them to transfer their research experiences into the classroom. Teachers engage in dialogues about contemporary engineering issues and visit industrial sites on field trips.

The outcomes of the summer research experience demonstrate the effectiveness of this program. Teacher understanding of the nature of engineering has increased through immersion in authentic engineering research experiences. Having the teachers develop inquiry-based learning activities built on their research experiences and current educational research on inquiry, learning styles, and diversity has been successful. By highlighting career information in the learning activities designed by the participating teachers, their students' knowledge about engineering careers has improved.

A representative classroom project developed by an E^3 participant focused on cell encapsulation for drug delivery. It was the culmination of a multi-week unit that covered scientific processes, graphing, data collection and analysis, living systems, chemistry and physics concepts. Each team was tasked to find a new way to encapsulate a drug. The students conducted experiments to create a feasible encapsulation with the correct properties. The encapsulation was to meet certain criteria depending on the classroom subject being taught. The expected outcome was that

the students would understand the engineering process, and how applicable science and math knowledge is to this process.

Using multiple performance metrics and evaluation techniques, the E^3 program has progressively developed into a program with demonstrated impact. . With 86 teachers participating to date, a substantial workforce has been tapped for disseminating engineering principles and appreciation. Ties between the cohorts are fostered through an annual Teacher Summit sponsored by the Colleges of Engineering and Science, as well through annual E^3 workshops during the academic year. Industrial support has resulted in subsequent internship opportunities. Many of the faculty/teacher relationships continue after the summer experience. Texas A&M University (TAMU) is actively recruiting the students of these teachers into the engineering program.

Introduction and Background

Rising Above the Gathering Storm[1] places a renewed emphasis on the need for teachers who will encourage students toward pursuing science, technology, engineering, and math (STEM) careers. For students to identify engineering as an education option, the engineering profession needs teachers who understand what engineers do as the problem solvers for society. The number of students entering careers in engineering, however, has been declining at the same time that demand for engineers is increasing[2].

The Enrichment Experiences in Engineering (E^3) for Teachers Summer Research Program established an important link between secondary schools and a society increasingly dependent upon science and technology. Studies found that many underrepresented students selected engineering as a possible career due to a high school teacher's recommendation[3,4]. Because "front line" impact is made by teachers, educating them about engineering and deepening their knowledge of engineering careers will encourage students to pursue the study of engineering and other STEM subjects.

Program Description

Overview

The E^3 Teacher program is funded by the National Science Foundation's Research Experience for Teachers (RET) program and is hosted by the College of Engineering (COE) at Texas A&M University (TAMU). The E^3 RET program is an integral part of the COE outreach plan and targets secondary STEM teachers across Texas. Since each teacher may reach 1000^+ students in his/her career, this initiative can have tremendous impact in encouraging young people into technology fields and preparing teachers to equip them for success in their journey. The goal of the outreach efforts is to increase the pool of engineering applicants and build a network to recruit partner teachers.

Although many RET programs focus on a single research area, the E^3 RET program provides access to engineering faculty across 12 departments, thus allowing for a better match of research areas with teacher interests and regional needs. It is a 4-week summer residential program that is designed to provide a comprehensive well-rounded experience.

Components of the E^3 RET program

To provide this comprehensive well-rounded experience, teachers participate in activities related to the E^3 RET objectives: 1) research and laboratory experience, 2) education theory and development of authentic inquiry-based engineering projects, and 3) engineering career awareness. Specifics associated with these objectives are outlined in the following paragraphs.

Objective 1: Engineering faculty mentors assist teachers in understanding the current status of emerging technologies and research and provide informal instruction in research methodology and science theory appropriate to the teacher's research experience. During the summer program, the teachers participate in research activities in their faculty mentor's lab. Each faculty mentor has a teacher team which consists of two math and/or science teachers. The research activities are tailored to the teachers' classroom courses, and each teacher develops a module of their research results into an activity or project for classroom implementation.

Objective 2: In support of the second objective, the E^3 RET program engages in several professional development activities based on the National Science Education Standards (NSES), which asserts that professional development activities for science teachers should provide opportunities for learning and various tools/techniques for both self reflection and collegial reflection [5,6]. A collegial community is developed where the participants are provided opportunities for interaction and information exchange, such as interactive seminars on learning and teaching[7]. Led by faculty in the TAMU University's College of Education and Human Development, the interactive seminars expose the teachers to leading edge 'culture and learning' research discussions.

Based on their engineering research experience, each teacher prepares instructional materials and hands-on learning activities/projects to integrate into their classroom[8]. The faculty mentor participation in this activity is essential to ensure good engineering science dissemination into the classroom. Engineering education specialists are available to help the teachers transfer their engineering research experience into classroom experiences, and assist in alignment with Texas standardized testing objectives and curricula objectives for the classroom materials. The E^3 teachers also develop testing materials to assess student impact[9]. The E^3 RET program provides support for supplies, curriculum materials, and small equipment; these funds can be used to help establish new activities in their classrooms. A representative classroom project is detailed in the Results section.

Objective 3: To introduce E^3 teachers to a wide variety of engineering applications and career opportunities, visits are scheduled to high tech industry plants. These visits provide an opportunity for teachers to experience first-hand what engineers do in industry, how engineering industry products are made, and how engineering impacts daily life. Importantly, the contacts made during these trips facilitate follow-up opportunities for the participants (e.g., student field trips to the industry sites and/or visits by industry representatives to the high schools). Another opportunity to expose teachers to the field of engineering includes weekly dinners in which a COE faculty member discusses his/her research on a high profile topic (e.g. alternative energy sources) and allows for casual exchange with the E^3 teachers.

Teacher recruitment and selection

The E^3 RET program uses multiple pathways for recruiting public school secondary mathematics and science teachers that has resulted in highly diverse cohorts each summer. The three primary strategies include 1) COE partner high schools, 2) referrals from previous E^3 teachers; and 3) nominations from first-year Engineering Living Learning Community (ELLC) engineering students. The partner high schools have high minority, high economic need student populations across the state, and are targeted as partners with a goal of increasing the number of underrepresented students in engineering at TAMU. The ELLC students are largely 1st-generation and underrepresented students. Although special consideration is given to applications from these three recruitment pools, specific applicant attributes and experiences are also considered. The E^3 RET application solicits personal information on the following: 1) teaching experience (including years of experience, subjects/courses taught - STEM subject required) and Texas teaching certification(s); 2) education level (degree(s) and major discipline); 3) past participation in other professional development programs, 4) past research experience, if any; and 5) engineering knowledge base (e.g., personal awareness of types of engineering/engineers, examples of engineering solutions that affect daily lives). The application essay requests additional information such as past and present professional leadership roles and experiences, but it also yields insight into subjective attributes such as enthusiasm towards participation in the E^3 RET program, as well as a proposed plan to take the E^3 experience back to their campus/ faculty/students, and other possible venues for dissemination.

Faculty mentor recruitment and participation

The COE has over 450 faculty, providing the flexibility and options to annually provide best matches to the E^3 participants with diverse backgrounds and interests. The faculty mentor recruitment strategy has matured over time. Initially, faculty participation was on a volunteer basis, but as enthusiasm quickly built within the COE, there are now more faculty members interested in hosting teachers than there are teachers to place. For example, 16 COE faculty specifically expressed interest in mentoring a 2008 E^3 participant although only 8 mentors were needed. The E^3 RET program actively recruits new faculty writing NSF CAREER proposals, offering the opportunity to incorporate this RET program into their educational outreach plan. This has proven to be successful for both the faculty and the RET program as these faculty are highly motivated for their teachers to excel.

Additional commitment for this RET program includes leveraging from existing programs within the COE. For example, the E^3 RET recently partnered with programs in aerospace engineering and nuclear engineering departments to host additional teachers. CAREER awardees have also requested supplemental funding that has increased the number of teachers participating in the RET. The 2008 E^3 RET program provided the administrative umbrella to facilitate these teacher research experiences, though their funding came from other sources. Such external funding will continue to be sought to achieve institutionalization of the E^3 RET program.

Results

The E^3 RET program is not a research project, and as such, there are neither research questions nor a research design. However, the E^3 program has goals and anticipated outcomes, and has used qualitative questions to measure these outcomes. The following paragraphs provide 1) information on the demographics of the participants and their school student populations, 2) outcomes of the three E3 program objectives, and 3) program impact on the participants and their students.

Data on the E^3 participants and their home institutions

Since inception, the E^3 RET program has hosted a total of 74 Texas in-service teachers from around the state: 37 from Houston; 1 from Dallas; 6 cities from South Texas; 30 from small towns in South Texas (average population < 5,000); and 12 preservice chemistry and math education students from TAMU (total 86 participants). The vast majority of the teachers had content-area degrees (32 in mathematics, 14 in biology, 10 in chemistry, 8 in physics, 6 in technology or engineering) and the remaining in multiple science content areas; 26 hold graduate degrees. E^3 RET teachers were 44% white, 30% Hispanic, 18% African American, 5% Asian, and 3% other, as compared to state-wide averages of 69% white, 20% Hispanic, 9% African American, 1% Asian, and 1% other. Forty-eight female and 38 male teachers participated. Table 1 presents ethnicity/gender breakdown.

Table 1: Participants by Gender and Ethnicity

	WF	WM	HF	HM	BF	BM	AF	AM	OF	OM	TOTAL
2003	4	4	2	0	1	1	0	0	0	0	12
2004	5	2	3	2	2	0	1	1	0	0	16
2005	4	2	2	1	1	1	1	0	0	2	14
2006	1	3	3	4	1	0	0	0	0	0	12
2007	2	2	4	2	2	1	0	0	0	1	14
2008	4	5	1	2	4	1	0	1	0	0	18
Total	20	18	15	11	11	4	2	3	0	3	86

Several teachers were from engineering magnet schools in Houston or South Texas which enroll large percentages of ethnic minority students. The South Texas schools serve a majority Hispanic (>90%) student body. In the schools represented by the in-service teachers, 88% of the students are Hispanic or African American and an average 77% of the students are economically disadvantaged. These percentages are weighted, based on the numbers of schools represented by each RET cohort. Table 2 presents the demographics for schools represented by each RET cohort.

To date, E^3 RET high schools have sent 139 students to the TAMU engineering program since their E^3 teacher(s) attended the RET program; additional students from these schools have enrolled in engineering programs at other universities as well. Teachers each received 60 hours of continuing education credit in *differential curriculum* for Gifted and Talented from the Texas Education Agency. Based on the E^3 RET objectives, some of the program outcomes are highlighted in subsequent paragraphs.

Table 2: Demographics of Participant Schools

Year	% Hispanic or Afr. Amer.	% Economically disadvantaged
2003	89	75
2004	95	83
2005	76	80
2006	98	90
2007	81	81
2008	64	64
Weighted Avg.	**88**	**77**

Outcomes for each E^3 program objective

Objective 1: *Offer teachers experiences with cutting-edge engineering research*. Faculty members from several engineering departments have participated in the E^3 RET program as faculty mentors (Table 3). Eighty percent of the four-week program is spent in faculty research areas, and the teachers report positive experiences from the research time with faculty. In an E^3 RET online survey, 94% of the participants anticipate interacting with their faculty mentor (via email, phone, etc) after their summer RET experience. As per one participant, "We are planning several visits - opportunities for interaction for students." E^3 teachers have indicated the importance of maintaining contacts with their mentors. Positive outcomes included subsequent faculty visits to high schools, receiving valuable information to present to high school classes (e.g., engineering applications for math classes), assistance with logistics in student visits to the university. The teachers value the network with collegiate educators.

Table 3: Engineering Faculty Mentors for the E3 Ret Program

Year	Aero.	Bio.&Ag.	Chem.	Civil	Elec.	Indus.	Mech.	Nuclear
2004	1	1		3	1	1	1	
2005	2	1		1	1	1	1	
2006	1			1	1	2	1	
2007	1		1				3	
2008	1		1	2	1		1	2

* 2003 information unavailable

Objective 2: *Transfer engineering research to secondary STEM classrooms through teacher development of authentic inquiry learning activities based upon their research experiences.* E^3 participants were tasked with developing a participatory engineering project for their high school classroom. As an example, one E^3 teacher developed a classroom project involving cell encapsulation for drug delivery. The teacher had participated in research activities in a chemical engineering laboratory where the faculty mentor's research involved various aspects of colloidal chemistry. The teacher was particularly intrigued by the cell encapsulation research, where the research team was focusing on the creation of colloidal crystals, the formation of disk-like colloid particles, and creating a protective membrane for encapsulation. The purpose of creating disk-like colloid particles is to study the shape and movement of these particles in fluids, which can be related to processes such as red blood cell movement and formation. The core element that the teacher wanted to take to the high school classroom was cell encapsulation, allowing

students to see the need for encapsulation, how drug delivery works, and the importance of semi-permeable membranes. The high school engineering project was the culmination of a multi-week unit that covered scientific processes, graphing, data collection and analysis, living systems, chemistry and physics concepts. Each student team was tasked with a hypothetical proposal: "A pharmaceutical company is looking for a new way to encapsulate a drug. Each encapsulation will need to have a semi-permeable membrane so that the medicine will be released into the "bloodstream" but not be attacked by the "immune system." The students conducted experiments to create a feasible encapsulation with the correct properties using their knowledge and skills. The encapsulation was to meet certain criteria depending on the classroom subject being taught. The students then defended the design of their encapsulation based on their research of their materials and the results they obtained from the experiments. An expected outcome was that the students would understand the engineering process, and how applicable science and math knowledge is to this process. The E^3 RET website provides a comprehensive set of lesson plans created by E^3 participants (http://essap.tamu.edu/e3/).

Objective 3: *Improve grade 8-12 students' knowledge about careers in engineering by highlighting career information in the learning activities designed by the teachers.* Exit interviews indicated that all 86 E^3 teachers changed their understanding of what engineering is and intended to discuss engineering in their classrooms to interest students in this career field. Two activities targeted to improve teacher awareness of engineering careers included the weekly industry field trips and the weekly dinners where various faculty members shared their leading edge engineering research. The industry field trip sites have included Applied Materials, Motorola, Sultzer Orthopedics, Lynntech, NASA, Schlumberger, South Texas Energy Plant, and Sand Hill Energy Center, Neutral Posture, as well as opportunities on the university campus (e.g., High Bay Structural Materials Testing Laboratory, Visualization Laboratory College of Architecture, Texas Transportation Institute, BioMass Laboratory College of Engineering, Wind Tunnel testing facility). Of the teachers surveyed, 90% indicated that the field trips enhanced their experience. Regarding one of the field trips, one teacher stated, "I received practical applications to take back to my classroom."

At the E^3 weekly dinners, a discussion was facilitated by a notable engineering researcher on a topic of interest to the public. These discussions were led by COE faculty members and some of the topics included alternative rescue engineering, sustainable energy, petroleum energy, and biomedical engineering research, motion planning algorithms and applications, biochemical reactions, food safety, fresh water production from oil field wastewater, alternative energy sources, global warming, public health problems, food radiation, TI-89 calculators, the Columbia shuttle accident, genetics and cloning, food safety, nanotechnology workshop, and understanding the tsunami. Of the teachers surveyed, 97% indicated that the informal discussions at the faculty dinners enhanced their summer experience. Regarding a guest faculty speakers, one teacher said, "An excellent presentation and a lab I would love for my student to visit. It is something the students could relate to with real-world applications."

<u>Program impact on E^3 participants and their students</u>

The E^3 RET program can easily be adapted in many locations in the U.S. Based on participant input on end-of-program surveys and at annual E^3 workshops, there is evidence of "implications

for practice" for the E^3 RET program. Outcomes can be qualitatively measured by addressing the following questions.

1. *Is there evidence that the E^3 participants had a better understanding of engineering careers at the conclusion of the RET program?* Participant comments during the workshops and in the surveys consistently indicated that the E^3 program has given them a better grasp of the breadth of engineering careers that exist. One teacher indicated "it made me have an open view about all the aspects of engineering." Another teacher stated that the overall E^3 experience was very good, and learning about all types of engineering was particularly valuable. One teacher discussed the re-integration of interests and the science of engineering which led to a better understanding of engineering disciplines. Repeatedly, the teachers stated that, in particular, the field trips, the tours of the E^3 faculty mentor labs, and the weekly dinner/lectures raised their awareness of the various engineering disciplines. 100% of the 2008 post-program survey responders indicated that the E^3 experience will allow them to promote the field of engineering to their students.
2. *Is there evidence that by participating in an engineering research laboratory and developing a classroom project based on that research, the E^3 teachers gained a deeper understanding of their teaching subject (e.g., chemistry, algebra, physics)?* Many teachers indicated that the engineering applications enhanced their understanding of how mathematics/science is integrated for practical applications. Whether their research topic was plastics deformation, shape memory alloys, composite materials, or biodegradation of xenobiotics, the E^3 experience allows the math/science teachers to enrich their lessons with engineering applications and thus heighten student interest. As such, they were able to promote the field of engineering along with promoting the math and science fields.
3. *Is there evidence that the E^3 program provided opportunities for the participants to help their students learn about admissions into the engineering program at TAMU?* Several teachers indicated that they were comfortable in contacting E^3 engineering faculty and/or the E^3 PI team to facilitate opportunities to share with their students (e.g., Powerpoint presentations, faculty guest speakers, other support) and to encourage students to apply to the TAMU engineering program. Several teachers suggested that students recognize the networking contacts that their teachers have with engineering faculty may indeed facilitate potential opportunities for the students, and in light of those connections, some students are willing to work more diligently on their coursework. One science teacher from a Texas-Mexico border city participated in the NSF-funded program at TAMU and subsequently participated in the E^3 program. At the current time, there are at least 9 students from her school who are enrolled in the TAMU engineering program. The school population is 90% minority and 78% economically disadvantaged. Moreover, it is particularly interesting that these students, who typically are not willing to live far from home, are attending a university that is over 300 miles away.
4. *Did the participants return to their home institutions and implement the developed lessons/project in their classroom?* Most teachers were able to implement some sort of engineering-oriented activity into their classroom curriculum. However, some teachers experienced barriers that prevented full classroom implementation (e.g., issues with scope and sequencing, time constraints due to state-mandated curriculum objectives, limitations on needed materials or equipment, etc.). One example of a highly successful classroom implementation involved a project on shape memory alloys which was presented to a physics class. The project was well received by the class, and one group of

students wanted to further develop the project for the state science fair. Ultimately, the students won first place at the district science fair, second place at regional science fair, and received a bid to participate in the Texas Science and Engineering Fair. These students (all Hispanic females) are currently attending Tier-one universities and are majoring in mechanical engineering.

Value of E^3 program to participants

It is also important to consider if the summer research experience was *valued* by the E^3 participants. If so, recruiting their colleagues to apply/participate in the RET program could be an indicator of 'teacher promotion of the E^3 program'. Repeatedly, teachers indicated that when they returned to their home campuses, they were excited to share their engineering research experience with their fellow teachers. Of the 44 secondary schools which have been represented by E^3 participants, 20 of them have been represented by at least two teachers during the six-year E^3 RET program. Moreover, for the Summer 2009 application pool, half of the applicants hail from schools previously represented by an E^3 participant. One teacher stated, "I have been able to go back to my classes and students and talk about the experiences I had here and now talk more about engineering. I have gotten other teachers to hear about it and they are excited too. I am the third person from my district to participant. Now I have other teachers in my district who are excited too. We're talk about having engineering classes (since my district did not have that already)."

Conclusions

The E^3 RET program has matured over its six years into an effective means of providing underserved ethnic student populations on exposure to engineering as a career option and how they might become engineers. Teaching teachers has proven an efficient approach in reaching a large number of students. By being highly selective, the teachers chosen ensure higher success in achieving the ultimate E^3 goal, which is to encourage more students into the STEM disciplines. Many of our participants have achieved greater professional success as a direct and indirect result of participating in this program. TAMU's College of Engineering has come to value this program so much that efforts are underway to institutionalize it.

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