Enrichment Experiences in Engineering (E^3) for Teachers Summer Research Program: An Examination of Mixed-Method Evaluation Findings on High School Teacher Implementation of Engineering Content in High School STEM Classrooms

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Abstract

Ongoing efforts across the U.S. to encourage K-12 students to consider science, technology, engineering and mathematics (STEM) careers have been motivated by concerns that the STEM pipeline is shrinking because of declining student enrollment and increasing rates of retirement in industry. The Enrichment Experiences in Engineering (E^3) for Teachers Summer Research Program at Texas A&M University engages high school STEM teachers in an engineering research experience so they can introduce engineering concepts through the courses they teach to their students and stimulate students to pursue engineering careers. This paper presents programmatic evaluation mixed-methods findings assessing the value of the E^3 program as a catalyst for STEM teachers' professional development in understanding the field of engineering and their perceived ability to implement engineering content into their high school STEM classes. Quantitative programmatic evaluation findings document that the E^3 program had a positive benefit for STEM teachers as related to their experiences in teaching and promoting the field of engineering to their students. Qualitative programmatic evaluation findings document two themes, "Positive Professional Development Growth" and "Short/Long-Term Benefits of Participation." Finally, recommendations are provided to high school STEM teachers and Colleges of Engineering to enhance their partnerships.

Introduction

For the U.S. to maintain global economic competitiveness, more citizens with engineering degrees are needed (U.S Department of Labor, 2007; National Academy of Sciences, 2007; Academy of Science, 2010). However, both engineering enrollments and degrees awarded began declining over two decades ago, despite more than 10 percent projected job growth in the engineering disciplines in the near future (National Science Board, 2008; Dohm and Shniper, 2007; National Science Board, 2010). Moreover, the engineering workforce of today does not reflect the nation's demographics: women, Hispanics and African Americans are underrepresented in engineering. In a field of predominantly white males, only 11 percent of engineers are female, and an even smaller percentage are minority (ie., 4 percent are African American, 6 percent are Hispanic) (Busch-Vishniac and Jarosz 2007; National Science Foundation 2009).

Similarly, in undergraduate engineering programs, only 20 percent of students enrolled are female and their share of the engineering degrees is approximately 17 percent (Chubin, May et al., 2005; Dedicated Engineer, 2006). For minorities, African Americans represent 6 percent of enrolled engineering students and a 5 percent share of the engineering degrees awarded, while Hispanic percentages are 7 percent and 6 percent, respectively (U.S. Department of Education, 2009; Chubin, May et al., 2005). Diversifying the engineering workforce should be a priority, not only to meet continuing demand, but to reflect the nation's population as well. With the changing demographics of our country, it is vital to recruit from minority groups, as well as women, to help satisfy projected engineering workforce needs.

To increase the number and diversity of students majoring in engineering, it is essential to improve exposure to this field during the K-12 academic years. Millions of dollars are spent each year in the United States to improve public understanding of engineering. However, research indicates that K-12 teachers and students typically have little understanding of the profession (Committee on Equal Opportunities in Science and Engineering, 2000; Cunningham and Knight, 2004; Cunningham, Lachapelle et al., 2005). Because "front line" impact is made by teachers, educating them about engineering and expanding their knowledge of engineering careers are critical to encouraging students to pursue this field. Since most high school math and science teachers have had little contact with engineering or related careers, it is not surprising that these teachers have misconceptions about engineering (Hoh, 2007). Lindsley and Burrows (2007) investigated changes in teacher attitudes about engineering before and after they participated in an introductory course in engineering design, and noted statistically significant positive changes in their confidence in basic engineering knowledge gained during the course. Also, teachers indicated that they better understood what it takes to be a successful engineer.

Dick and Rallis (1991) investigated factors and influences on career choices of high school students, and found the influence of "socializers" to be a major factor. "Socializers" (e.g, parents, teachers, counselors) significantly influenced high schoolers' career choices, particularly when selecting STEM careers (Dick and Rallis, 1991). For high school age students of color, teacher support is particularly important in their decisions regarding post high school education (Pope and Fermin, 2003; Nora, 2004; McWhirter, Torres et al., 2007). Studies found that underrepresented college students who selected engineering did so because of a high school teacher's recommendation (Rinehart and Watson, 1998; Lovencin, Najafi et al., 2007). Trenor et al. (2008) conducted in-depth surveys and interviews with female engineering students of color at the University of Houston, an institution with a highly diverse student population where no ethnic group is a majority. They found that high school teachers were a valuable resource to students of color providing both information about the different engineering majors and encouragement.

Although public perception is part of the problem, little exposure to engineering principles and design through formal K-12 curricula is also a fac-

tor contributing to the general lack of understanding of engineering and what engineers do. After the National Research Council (NRC) developed and disseminated the National Science Education Standards, Fadali and Robinson studied the standards to determine if the teaching of engineering principles and design was supported (National Research Council, 1996; Fadali and Robinson, 2000). Fadali and Robinson (2000) concluded that although the standards emphasize the importance of coordinating mathematics and science programs, engineering and technology were not identified as a logical means to do so. Moreover, they indicated three obstacles in accomplishing this task: 1) inadequate teacher preparation, 2) discrepancies between state and national standards, and 3) inadequate K-12 science textbooks (Fadali and Robinson, 2000). The NRC examined ways to bring engineering into the K-12 classroom, and put forth suggestions to key stakeholders regarding K-12 engineering curricula and instructional practices (National Research Council, 2009). The committee distilled their suggestions down to three primary options: 1) *ad hoc* infusion, 2) stand-alone courses, and 3) interconnected STEM education. Since it requires no significant changes in curricula administration or structure, *ad hoc* infusion of engineering ideas and activities (e.g., design projects) into existing mathematics, science or technology curriculum is regarded as the most direct and least complicated option. Moreover, it is a commonly practiced outcome for teachers participat-

Table 1. E^3 Program Objectives

Objectives of E^3 program at TAMU
Approach to Research Training (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. Working in pairs, the teachers participate in research activities in their faculty mentor's laboratory.
Research Integration Component (Objective 2): Based on their engineering research experience, each teacher prepares instructional materials and hands-on learning activities/projects to integrate into their classroom curriculum. Engineering education specialists are available to support this effort. In addition, basic instruction on the engineering design process is provided.
Engineering Career Awareness (Objective 3): Various activities are provided to broaden teacher awareness of engineering career opportunities. Field trips to high-tech industry plants allow the teachers to see firsthand what engineers do in industry, and how engineering impacts daily life. Also, opportunities to further expose teachers to various engineering fields include 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.

Table 1. E^3 Program Objectives

E^3 Summer Program

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday
Week 1					
11:30-1:30 Dormitory check-in **4:00-6:00** Orientation, Mixer, and Dinner	**9:00** Meet outside dorm **9:15** E3 Cohort photo **9:30-10:45** Campus Tour **10:45-11:30** Tour of Engineering **11:30-1:00** Teacher Expectations; Meet your faculty mentor; Lunch provided **1:00-2:45** Lab Research* **3:00-3:30** Educational Discussion Session **3:30-5:00** Engineering Design Lecture	**8:30-3:00** Lab Research* **3:00-4:30** Engineering Design Lecture **5:00-7:00** Dinner Speaker Series: faculty member presents research topic	**8:30-10:00** Engineering Design Lecture **10:00-3:00** Lab Research* **3:00-5:00** Educational Discussion	Group A # **8:30-10:00** Local Industry Tour **10:00-3:00** Lab Research* Group B # **8:30-10:00** Lab Research* **10:30-12:00** Local Industry Tour **12:00-3:30** Lab Research*	**8:30-3:00** Lab Research*
Week 2					
	8:30-3:00 Lab Research* **3:00-3:30** Educational Discussion **3:30-5:00** Engineering Design Lecture	**8:15-12:15** (Two Concurrent Sessions) What's the Research Question? 20 min presentations each teacher **1:00-3:00** Lab Research* **3:00-4:30** Engineering Design Lecture **5:00-7:00** Dinner Speaker Series: faculty member presents research topic	**8:30-10:00** Engineering Design Lecture **10:00-3:00** Lab Research* **3:00-5:00** Educational Discussion	**7:30** Meet in front of dormitory to load vans **10:00** Out-of-town Industry Tour	**8:30-11:30** Lab Research* **12:30-3:00** Faculty Lab Tours
Week 3					
	8:30-3:00 Lab Research* **3:00-5:00** Educational Discussion	**8:30-3:00** Lab Research* **3:00-4:30** Educational Discussion **5:00-7:00** Dinner Speaker Series: faculty member presents research topic	**9:00-12:00** Presentation on "University" Engineering Programs, Admissions, Etc. **12:00-3:00** Lab Research* **3:00** **5:00** Educational Discussion	**7:30** Meet in front of dormitory to load vans **10:00** Out-of-town Industry Tour	**8:30-11:30** Lab Research* **12:30-3:00** Faculty Lab Tours
Week 4					
	8:30-3:00 Lab Research* Practice Run for Symposium **3:00-5:00** Educational Discussion	**8:30-3:00** Lab Research and Lab Wrap Up* (last day in lab) **3:00-4:30** Educational Discussion **5:00-7:00** Dinner Speaker Series: faculty member presents research topic	**8:30-3:00** E3 Symposium **3:00-5:00** Educational Discussion wrap-up and Program Evaluation survey	**9:00-11:00** Program Closure **11:30-1:00** (University Club) Celebration Luncheon **1:30-2:30** (Dormitory) Check out & return key and access card	

* Lab Research conducted in faculty mentors' laboratories

Figure 1. Sample Schedule for E^3 Summer Program

ing in professional development programs.

The Research Experience for Teachers (RET) in Engineering Program was created by the National Science Foundation (NSF) over a decade ago. The program goal is to help build long-term collaborative partnerships between K-12 STEM teachers and the university research community to provide opportunities for teachers to be involved in engineering research and help them translate their experience into classroom activities. One of the NSF-funded RET projects is the Enrichment Experiences in Engineering (E^3), which is hosted by the College of Engineering (COE) at Texas A&M University (TAMU). The E^3 program was initiated in 2002, and models the *ad hoc* infusion strategy for incorporating engineering into the K-12 curriculum. This paper provides information on the E^3 program at TAMU, as well as program impact on STEM teachers in high school settings.

The Enrichment Experiences in Engineering (E^3) Program

Overview

The E^3 program is designed to bring high school science and mathematics teachers to the TAMU campus for a four-week summer residential experience where the teachers are mentored by engineering faculty. The teachers were provided with the following experiences during the program: (a) hands-on participation with current engineering research, (b) awareness of engineering career opportunities for their students, and (c) development of an engineering project for implementation in their classroom. Since each teacher may reach 1000-plus students in his/her career, this initiative has the potential for tremendous impact in encouraging young people into engineering.

The E^3 program is an integral component of the COE's comprehensive outreach plan, which has the overarching goal to increase the pool of undergraduate engineering applicants into the COE, as well as to build a network to recruit partner teachers. Since 2002, recruiting of teachers from majority-minority high schools has resulted in a large community of engineering literate STEM teachers that have formed clusters in their school districts. As part of the college's student recruitment plan, 12 Texas high schools with high minority, high economic-need student populations have been targeted as partners with a goal of increasing the number of underrepresented students in engineering at TAMU. This "Engineering 12" effort started in 2008; these schools have regular interaction with the COE through student recruitment activities, and teachers from these schools are encouraged to apply for participation in the E^3 program. This college level outreach initiative is strategically coordinated with the college recruitment and retention efforts, which significantly leverage the relationships built with the teachers and administrators. In addition to the E^3, the COE's outreach initiative also includes an annual TAMU Teacher Summit for STEM teachers, as well as a Teacher Advisory Council.

When selecting teachers to participate, the E^3 program uses various means for recruiting public high school mathematics and science teachers, including: 1) COE partner high schools, 2) referrals from previous E^3 teachers, and 3) nominations from first-year Engineering Living Learning Community (ELLC) students. When applications are reviewed by the E^3 team, specific applicant attributes and experiences are also considered (e.g., teaching experience, education level, past participation in other professional development programs, etc). Also, the applicants are required to submit an essay which 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 program, addressing questions such as why they want to participate, and what they hope to gain by participating in E^3. The essay also provides information on the applicant's dissemination potential by requesting a proposed plan to take the E3 experience back to their campus/faculty/students, as well as other possible venues for dissemination. The E^3 team reviews and ranks the applicants; participant selections are based on the rankings.

Over the 10 years of the E3 program, 137 high school teachers (2003-2012 E^3 cohorts) have participated in the program. The participants came from schools located in various parts of Texas, including 28 schools in Houston, five (5) schools in San Antonio, four (4) schools in Dallas), 18 schools in the South Texas region, and 20 schools in more rural areas of the state. Collectively, these schools average 83 percent Hispanic and/or African American student populations and 71 percent economically-disadvantaged. The participant demographics of the 10 E^3 cohorts were averaged 50 percent White, 26 percent Hispanic, 16 percent African American, and 12 percent Other. This compares to statewide percentages of 64 percent White, 24 percent Hispanic, 9 percent African American for all K-12 teachers in the State of Texas (Texas Education Agency, 2011). As to gender, 55 percent of the participants were female and 45 percent were male.

Components of the E^3 RET program

Although many RET programs across the country focus on a single research area, the E^3 program at TAMU offers access to engineering faculty across 12 departments, providing a broad breadth of projects and allowing for a better match of research areas with teacher interests and regional needs. The comprehensive and well-rounded experience unfolds over a four-week summer session during which the teachers participate in activities related to the E^3 objectives: 1) research and laboratory participation, 2) education theory and development of authentic inquiry-based engineering projects, and 3) engineering career awareness. A brief summary of the program objectives and associated activities is outlined in Table 1, and a sample E^3 schedule is presented in Figure 1. Additional program details can be found in Autenrieth et al. (2009).

Methods

The purpose of this study was to examine the impact of the E^3 program at TAMU utilizing program evaluation data over multiple years from various teacher cohorts. Additionally, the research team sought to answer the following research question: *What are high school teachers' views of the impact of the E^3 program in integrating engineering content into their high school STEM courses?* To answer this question, the research team incorporated a mixed-methods design to obtain data from cohorts of teachers that participated in the E^3 program from 2003-2007. For quantitative data to inform this study, a total of 28 teachers (41 percent response rate) responded to a program evaluation survey that sought to understand teacher success in implementing engineering content into their high school STEM curriculum. This survey was administered in the summer of 2007. An e-mail was sent to all teachers that participated in the E^3 program for 2003-2007 requesting their voluntary participation. No identifying information was requested of teachers during the on-line survey.

To obtain qualitative data via retrospective interviews (Reiff, Gerber & Ginsberg, 1997), program officials invited teachers from previous cohorts to TAMU for focus group interviews to understand the success/challenges of implementing engineering content into their high school STEM courses. A total of 24 teachers came to TAMU to participate in focus group interviews. The external evaluator facilitated these focus groups. No program officials were present during the focus group interviews. The demographics of the teachers that participated in the focus group interviews are provided below in Figure 2:

Results

Using a mixed-methods approach to the responses from the high school STEM teachers who participated in the E^3 program, this study assessed the value of the E^3 program as a catalyst for STEM teachers' understanding of the

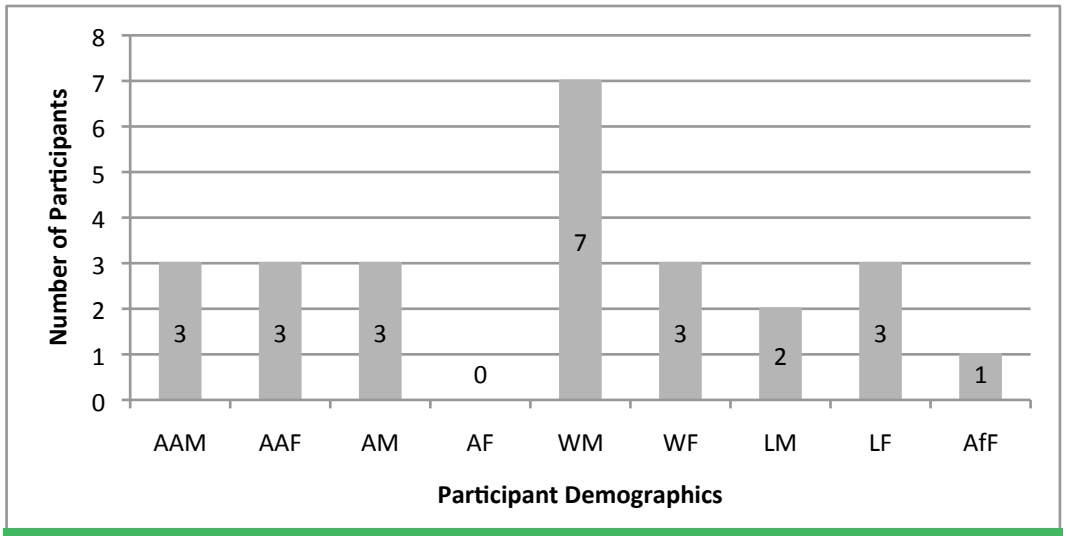

Figure 2: Teacher Demographics of Focus Group Participants

Note: AAM = African American Male; AAF = African American Female; AM = Asian Male; AF=Asian Female; WM = White Male; WF = White Female; LM = Latino Male; LF = Latino Female; AfF = African Female

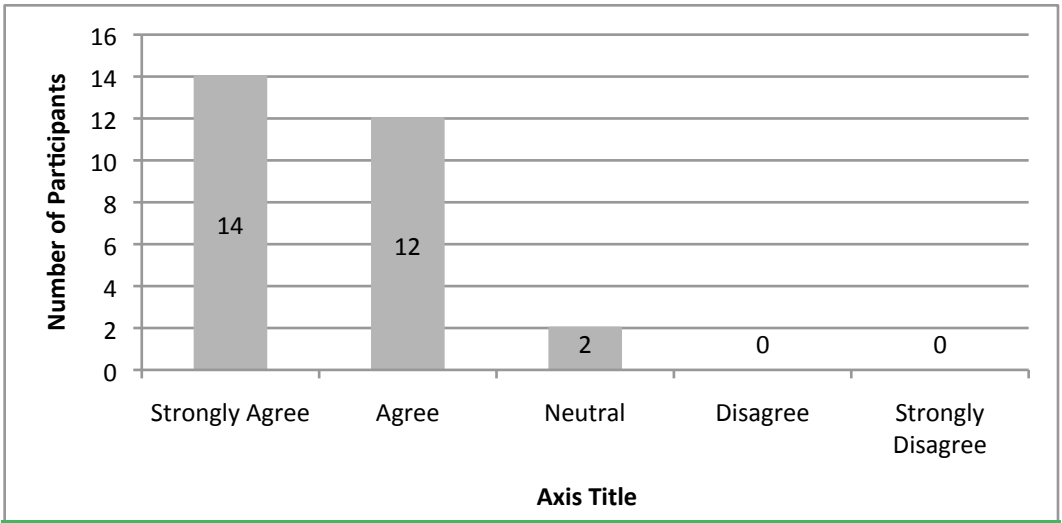

Figure 3: Benefit for STEM teachers related to implementing engineering content into their high school STEM courses

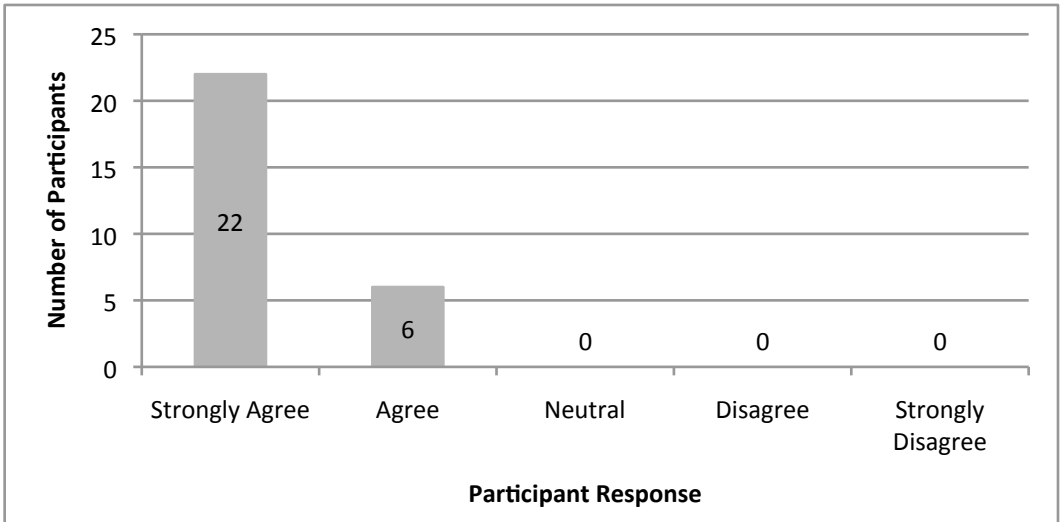

Figure 4: Promotion of the Field of Engineering to their Students

field of engineering and their perceived ability to implement engineering content into their high school STEM classes. Responses from the online survey highlight the impact of the E³ program as a catalyst for STEM teachers understanding the field of engineering and their ability to implement engineering content into their high school STEM classes.

Quantitative Findings

The quantitative findings focused on two specific areas: (1) benefit for STEM teachers as related to their experiences in teaching, and (2) promoting the field of engineering to their students. Figures 3 and 4 provide data related to the quantitative findings related to these areas:

Fourteen (14) teachers selected the 'strongly agree' option documenting that attending the E³ RET summer experience had a positive effect on their teaching. Another 12 participants indicated selected the 'agree' option as well. In total 26 of the 28 respondents have positive comments related to this area of focus. Only two (2) participants selected the 'neutral' option and zero (0) participants selected 'disagree' or 'strongly disagree'.

We found that of the teachers that responded to the online survey, many have been better able to promote the field of engineering to their high school students (Figure 4). All 28 teachers selected either the 'strongly agree' or 'agree' option for this question. This is encouraging, given that teachers are leaving this experience with a new knowledge base of what the field of engineering encompasses so they can ultimately expose their students to the engineering discipline options available if they select this field as a college major.

Qualitative Findings

Two emergent themes characterized the responses of high school STEM teachers that participated in the E³ program. These themes included "Positive Professional Development Growth" and "Short- and Long-Term Benefits of Participation." Below the two themes are developed, and then, following a discussion of the findings, the ideas for improving future E³ programs are provided.

Positive Professional Development Growth

The most powerful theme that characterized the experiences of the STEM teachers that participated in this study was the sense of the Positive Professional Development Growth from the E^3 program at TAMU. The comments of participating teachers underscored the positive perceptions of this program. Note the common feelings of professional development growth in the remarks of several participants in this study:

- *It allowed me to work with a professor in a field that is interesting and intriguing. It gave me a long experience with the tools that are used in the universities and in the real world allowing me to collect data and information that I can share with my students.*
- *It made me have a much broader view about all the aspects of engineering……. and what they need to do or know in order to get into some of these programs.*
- *I had an overall good experience but mostly what I got out of it was just finding out all the different types of engineering that's available.*
- *It helps me want to continue to teach and learn to teach and be a better teacher and try to get everybody to move on to college and better themselves.*
- *I think one of the major positives that I got out of the program was seeing all the different applications and all the things going on in engineering. Looking at everybody else's projects, you get an overall vision of possibilities for students and ways to incorporate many different ideas into your classroom. And you can advise kids sometimes if they're interested in something.*
- *It's got me more involved, it's kind of revitalized my energy and my interests into trying to pursue these kids or trying to influence these kids to go into engineering.*

STEM teachers who participated in this program had positive comments about the professional development they received from participating in the E^3 RET summer program. These comments provide a 'snapshot' of the impact that a program such as the E^3 can have on teachers if given the proper exposure to the field of engineering.

Short- and Long-Term Benefits for Students

In the focus groups, participants were asked to consider the short and long-term benefits for their students as a result of the teachers having participated in this E^3 RET summer experience. Participants provided the following thoughtful comments:

- *Short-term is like a reintegration of the interests and the sciences of engineering and a better understanding of what else is out there besides my pre-experience knowledge. Long-term, hopefully more of my students are turned on to the area of engineering and pursue – not only pursue, but also achieve degrees in engineering, and not only undergraduate, but graduate work. Hopefully they would be influenced by telling them the experiences of what's out there and have you thought about this, because kids where I come from, they have limited experiences.*
- *The short term is a quick exposure to the areas of engineering of what is available in this field and long-term is that the experience of being here continues to linger and impact my teaching, my quality of teaching.*
- *I have been able to go back to my classes and my students to talk about what experiences I've had here and now there is talk more about engineering. I have gotten other teachers also to hear about it and they're excited about it too. We're even talking about maybe having engineering classes since my school district did not have that already.*
- *Short-term for me, as teachers continue to promote the engineering field, promote the math and science fields. Long-term wise, I love teaching, but I see myself promoting something more than just this – you know than just as a teacher. I've always considered maybe a program down there that can – one can institute along with maybe Texas A&M University where we're put together with University of Texas in Brownsville and develop something so that we can encourage these students.*
- *The short term is a quick exposure to the areas of engineering of what is available in this field and long-term is that the experience of being here continues to linger and impact my teaching, my quality of teaching. Before coming to this program I hadn't talked to my students about the opportunity – after this program I have continued to talk to my students about studying engineering*

Based on the comments from teachers that participated in the E^3 program, we find various short and long-term benefits of their participation. Probably the two most important realizations that emerged is that: 1) classroom teachers are provided with an opportunity to broaden their knowledge-base on engineering content and its importance to society, and 2) students' chances of receiving instruction about the field of engineering and various engineering professions can be greatly increased because of the opportunities that the E^3 program provides to its teachers. These short- and long-term benefits are especially important to diversify and meet the demand for engineers in the future.

Discussion

One of the biggest challenges associated with maintaining a strong U.S. economy is improving K-12 science and mathematics education, as illustrated in *Rising Above the Gathering Storm* report (National Academy of Sciences 2007). In this study, we have documented how the E^3 program at TAMU is addressing a much-needed priority in our nation's schools by increasing STEM teachers understanding of what engineers do. As previously mentioned, high school teachers who participated in this project were specifically from science and mathematics fields and were able to select from 12 engineering disciplines to focus on during their summer experience. This was vital as the research demonstrated that K-12 teachers typically have a limited understanding of the engineering profession and coupling their teaching endeavors to their research experiences reinforced their understanding (Committee on Equal Opportunities in Science and Engineering, 2000; Cunningham and Knight, 2004; Cunningham, Lachappelle and Lindgren-Streicher, 2005).

Another important issue addressed in this study was the lack of diversity in the engineering profession. Our literature review revealed that the diversity among the ranks of college students and the current workforce is moving at a snail's pace. In many instances, K-12 students who attend high-minority and low socioeconomic status (SES) schools are rarely exposed to engineering content and frequently have less exposure to advanced level science and mathematics classes that are essential for admission at the university-level (Wilson, 2000; Barton, 2003; Chubin, May et al., 2005) . More importantly, in many high-minority and low SES schools, there is a higher percentage of science and mathematics teachers of color.

The field of engineering cannot underestimate the importance these teachers have on the students of color that attend their schools. We have learned from the research literature that one of the 'socializers' (i.e., teachers) has a major influence on the college majors that students of color pursue. As a result, the E^3 program made it a priority to recruit teachers from highly diverse schools across the state to participate in a summer experience to have a greater effect on their 'college major' selection once they entered college.

Finally, we have learned from the research literature and the E^3 program at TAMU that concentrated efforts must continue if we are to increase the pipeline

of students, specifically, students of color and women from the United States. If not, the engineering profession will not reflect the diversity of the community that it serves and the benefits that a diverse community can bring to any profession. By doing so, a diversity of thought can be translated into outstanding innovations and new knowledge to better serve the needs of our nation and the world.

Recommendations

As a result of the current status of the research literature and the findings of this programmatic evaluation study, the following recommendations are warranted:

High School STEM Educators

1. We recommend that high school educators, specifically those in science and mathematics, attend programs that provide exposure to the field of engineering.
2. We recommend that teachers exposed to 'engineering enrichment' programs be provided with the appropriate time and space to adequately plan for engineering content to be infused into their course curriculum.

College of Engineering

The following recommendations are provided for representatives in colleges of engineering:

1. Partner with STEM teachers in high-minority and low-SES schools to demonstrate to a wider range of students what the field of engineering can offer and how to prepare while in high school to study engineering in college.

2. University and public school partnerships require resources. Continue to pursue funding opportunities from the National Science Foundation and other funding agencies to expose high school STEM teachers to engineering professions and content. This exposure can have a great impact on student selection of a college major.

Acknowledgments

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