Long-Term Impact of the Enrichment Experiences in Engineering (E[3]) Summer Teacher Program

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Abstract

The Enrichment Experiences in Engineering (E[3]) summer teacher program is hosted by the Dwight Look College of Engineering at Texas A&M University and is designed to provide engineering research experiences for Texas high school science and mathematics teachers. The mission of the E[3] program is to educate and excite teachers about the field of engineering so that they can introduce engineering concepts to their students and encourage them to consider a career in engineering. The E[3] program received funding from the National Science Foundation (NSF) Research Experiences for Teachers (RET) program from 2003 through 2013, and during that time, a total of 150 teachers participated in the program. Most of the teachers were from schools with large minority-student populations (average 83% Hispanic and/or African American; average 69% economically-disadvantaged). This paper presents evaluation findings to assess long-term impact of the E[3] program on teachers who participated in one of the NSF-funded E[3] programs during the 2003-2012 timeframe. The two research questions central to the study design were (1) What is the long-term impact of the E[3] summer program on teachers who participated in the program? and (2) To what extent did the teachers who participated in the E[3] summer experience impact student understanding, awareness and perceptions of the engineering field? The assessment tools included a series of focus group interviews and an anonymous online survey. The focus group sessions were conducted by the E[3] external evaluator during annual E[3] workshops where teachers from previous E[3] cohorts were invited to attend. The anonymous online survey was administered in Fall 2013 by the external evaluator. Evaluation findings document that the E[3] program has been successful in educating teachers about the engineering field and that, in the long term, teachers continue to promote engineering to their students as a career option. However, the teachers have experienced challenges when trying to implement their E[3]-developed classroom lessons in subsequent academic years. Recommendations to remediate this issue are provided. Although NSF funding concluded in 2013, the College continues to offer E[3] research experiences to high school mathematics and science teachers using other financial resources.

Keywords: engineering, K-12, teacher research experience

Introduction

Ensuring that the U.S. has a strong technical workforce is critical to preserve the country's global economic competiveness (National Academy of Sciences, 2007; US Department of Labor, 2007), and graduating more students with engineering degrees is essential for the U.S. to keep its competitive edge (National Academy of Sciences, 2007). However, the number of undergraduate engineering degrees awarded has remained relatively flat over the years, and the percentage of engineering degrees awarded to students from underrepresented groups (e.g., women, Hispanics, African Americans) is well below parity (National Science Foundation, 2009; National Science Foundation, 2011; National Science Board, 2014).

Encouraging more students to pursue engineering degrees is essential to satisfy future engineering workforce needs and teachers can be effective advocates in this endeavor. Teachers are influential in career choices for high school students, particularly STEM careers (Pope and Fermin, 2003; Nora, 2004), and are especially helpful for females and underrepresented minority students (Lovencin et al, 2007; Trenor et al., 2008).

The National Science Foundation (NSF) recognized the influence of high school teachers on student career choices when establishing the Research Experiences for Teachers (RET) in Engineering and Computer Science Program (National Science Foundation, 2011). One such RET program at Texas A&M University (TAMU), Enrichment Experiences in Engineering (E[3]), offers an engineering research experience for participating teachers, broadens their awareness of engineering careers, and provides support to the teachers as they develop an engineering-related activity for classroom implementation.

In this paper, the E[3] RET program's *long-term impact* on participating teachers is evaluated. Specifically, the impact on their teaching and their efforts to increase their students' awareness of engineering and engineering careers is assessed. Few programs have longitudinal studies that include teacher learning of new subject matter through professional development and teacher implementation of that subject matter within the confines of the K-12 classroom.

Background

Engineering in the K-12 Classroom

The National Science Education Standards (NSES) call for authentic inquiry activities in the K-12 science classroom while also emphasizing the importance of coordinating mathematics and science programs (National Research Council, 1996). Engineering curricula provides a logical means to coordinate these two programs and introducing engineering concepts in the classroom would also align with the call for more authentic inquiry activities (Fadali and Robinson, 2000).

In general, most K-12 teachers and students have marginal awareness of the engineering profession (Cunningham et al., 2005; Baker et al., 2006). There is minimal, if any, exposure to engineering concepts in the formal K-12 curricula. Several years ago, the National Research Council investigated practices to bring engineering into the K-12 classroom, and distilled their suggestions into three primary options: (a) *ad hoc* infusion, (b) stand-alone courses, and (c) interconnected STEM education (National Research Council, 2009). Requiring minimal changes in curriculum structure, the *ad hoc* infusion of engineering ideas and activities into existing mathematics, science or technology curricula is regarded as the most direct and least complicated option. Stand-alone engineering courses present more challenges for implementation (e.g., course approval at the local/state levels, professional development for teachers, etc.) Fully interconnected STEM education utilizes engineering skills and concepts to leverage natural connections between STEM subjects; however, much research would be needed to develop, test, and assess the curricula, etc. The E[3] program models the *ad hoc* infusion strategy by requiring participating teachers to develop an engineering-related inquiry-based activity for implementation into their high school math/science curriculum.

Review of Literature

Professional Development For Teachers

The NSES addresses professional development for science teachers and proposes "learning science content through the perspectives and methods of inquiry" (National Research Council, 1996). In very basic terms, inquiry-based learning is a natural process that evolves from the learner's curiosity. The learner asks questions that lead to a desire for answers (or solutions to a problem) and result in exploration to find the answer or solution. It is important that teachers have inquiry-based learning opportunities similar to their students (National Research Council, 1996). Caton et al. (2000) found that teachers who participated in inquiry-based experiences had greater confidence in teaching with the inquiry method and actually used it more frequently in the classroom. Other professional development programs for teachers that focused on inquiry-based learning had similar findings (Feazel and Aram, 1990; Dresner and Worley, 2006; Silverstein et al., 2009).

Aligning with NSES guidelines of inquiry learning for teachers, the NSF RET program was designed to provide engineering research experiences for teachers. Teacher research supports lifelong learning and intellectual rigor (Caton et al., 2000), and engaging teachers in real-world research allows them to increase their knowledge and skills in a technical field (Dresner and Worley, 2006). Also, teacher participation in research has been linked to improved student scores in science (Silverstein et al., 2009).

The Enrichment Experiences in Engineering (E^3) Program

The E^3 RET program at Texas A&M University engaged in several professional development activities based on the 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 (National Research Council, 1996). The program design reflected several attributes associated with strong positive professional development including (a) support beyond the E^3 summer experience to encourage a "community" of E^3 teachers (Dresner and Worley, 2006), (b) an extensive number of required contact hours (Garet et al., 2001), (c) a required end-of-program product that is held to some level of accountability (Jeanpierre et al., 2005), and (d) opportunities for teachers to become part of a learning community that allows them to explore and problem solve in teams (LaChance and Confrey, 200[3]).

The E^3 Program was a four-week summer residential program at Texas A&M University where high school science and mathematics teachers were matched with Texas A&M engineering faculty and participated in a research experience. All program activities were related to the E^3 RET objectives: 1) research and laboratory experience, 2) engineering career awareness, and [3]) education theory and development of authentic inquiry-based engineering projects. Each faculty mentor had a teacher team which consisted of two math and/or science teachers; the research activities were tailored to the teachers' classroom courses. To increase engineering awareness, the E^3 teachers were exposed to a wide variety of engineering applications and career opportunities. For example, field visits were scheduled to high tech industry plants, providing opportunities for teachers to experience first-hand what engineers do in industry, how engineering industry products are made, and how engineering impacts daily life. During the four-week program, teachers received educational instruction on the engineering design process, and subsequently developed a hands-on learning activity/project for implementation into their classroom that centered on the research they participated in and required the students to use the engineering design process. For example, two science teachers from a south Texas high school participated in cell encapsulation research. The teachers developed an E^3 classroom project where student teams were asked to use the engineering design process when tasked with this hypothetical proposal: *"A pharmaceutical company is researching a new method 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."* Based on outlined parameters and supplied with a variety of low-cost materials, the student teams created and conducted experiments to design a feasible encapsulation with the correct properties using their knowledge/skills and "defended" their design to the teachers and their classmates. Expected outcome: students understand the engineering design process and how applicable math/science knowledge is to the process.

During the 2003-2013 timeframe, 150 teachers (48% White, 27% Hispanic, 15% African American, 9% Other) participated in the program; most E^3 teachers were from schools with a high percentage of underrepresented minority student populations (average 83% Hispanic and/or African American; average 69% economically-disadvantaged). Additional program details are provided in previous publications (Autenrieth et al., 2009; Page et al., 2013).

Page et al. (2013) details the first evaluation effort to assess long-term impact of the E^3 program on participating teachers. The research team incorporated a mixed-methods research design to obtain data from the first five cohorts of teachers, and concluded that the E^3 program had positive benefits for teachers as related to their teaching experiences and promoting engineering to their students. The study presented in this paper is a second evaluation effort to assess *long-term impact* of the E^3 program.

Methods

Expanding the effort to assess long-term program impact, the E^3 team developed another mixed-methods research design to obtain data from teachers who participated in one of the E^3 summer programs during the 2003-2012 timeframe. The assessment tools included: (1) a series of focus group interviews and (2) an online survey. The two research questions central to the design were:

1. What is the long-term impact of the E^3 summer program on teachers who participated in the program?
2. To what extent did the teachers who participated in the E^3 summer program impact student understanding, awareness and perceptions of the engineering field?

Focus Group Interviews

The focus group interviews were conducted during three of the annual E^3 Workshops. These half-day workshops were hosted on campus during each academic year (typically late January) and became an integral mechanism to build and maintain a network of E^3 teachers. In addition to participation in the focus group interviews, attending teachers were provided face-to-face opportunities to stay connected with the E^3 Team, former faculty mentors, and fellow E^3 teachers. Attendees received updates regarding TAMU College of Engineering, shared their E^3 lesson plans and experiences with implementation, and created new connections with teachers from other E^3 cohorts. Table 1 provides E^3 Workshop attendance information.

Focus group interviews were conducted during the 2008, 2010, and 2011 E^3 Workshops (cumulative total of 41 teachers.) As teacher attendance increased substantially at subsequent E^3 workshops, the focus group format became unwieldy and less effective. So in 2012, the focus group format was replaced with a breakout-group format. Findings from the breakout sessions were mostly formative in nature (as opposed to summative), and are not included in this paper.

To obtain qualitative data via retrospective interviews (Reiff et al., 1997), workshop attendees participated in focus group interviews to shed insights regarding: (a) the successes/challenges of implementing engineering content into their high school STEM courses, and (b) program impact on the teachers (and indirectly) their students. The E^3 program external evaluator facilitated these focus group

Year of E^3 Workshop	Number of Attendees	E^3 Cohorts Represented
2008	11	2003, 2004, 2005, 2006, 2007
2009	7	2003, 2007, 2008
2010	9	2006, 2007, 2008, 2009
2011	21	2006, 2007, 2009, 2010
2012	31	2006, 2007, 2008, 2009,2010, 2011
2013	40	2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012

Table 1: Attendees at Annual E^3 Workshops

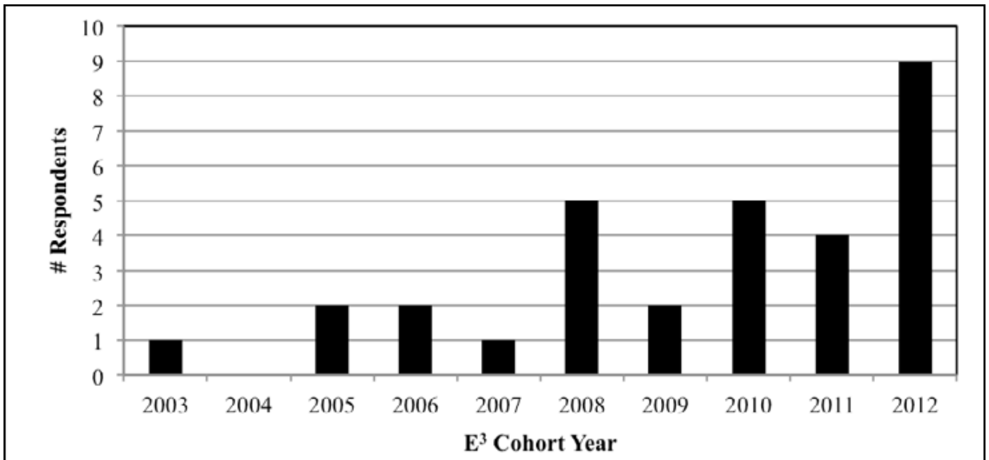

Figure 1: E^3 Cohort Year of Survey Respondents

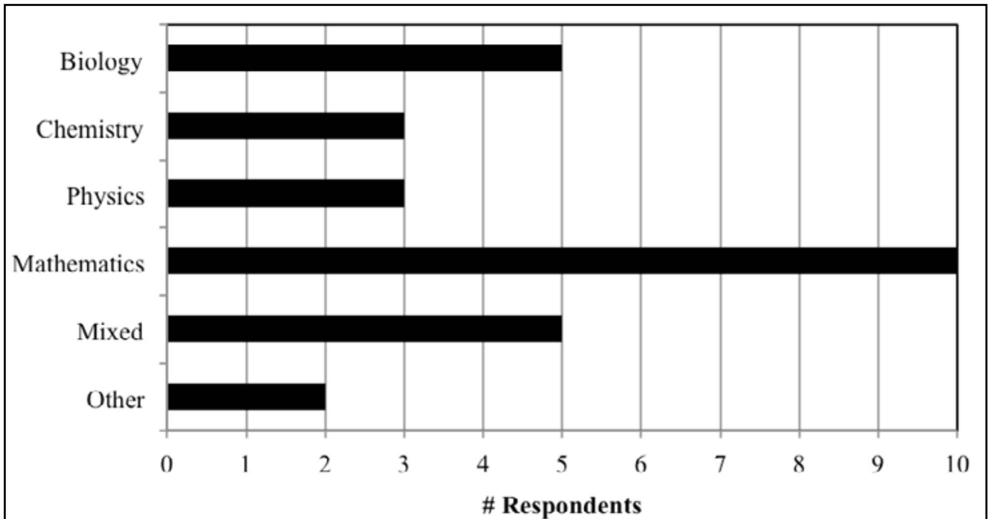

Figure 2: Subject Content of E^3 Classroom Lesson

interviews; no E^3 program officials were present during the interviews. Each focus group session was an hour in length; the sessions were recorded via audiotape and later transcribed. The specific focus group questions associated with long-term program impact included the following:

- What have been the long-term benefits for you as a teacher?
- What have been the long-term difficulties for you as a teacher, particularly as they relate to challenges/barriers associated with classroom implementation of your E^3 lesson?

Long-Term Impact Survey

The E^3 team complemented the qualitative nature of the focus group interviews by adding a quantitative online survey for distribution to former E^3 participants. Focusing on the two research questions, an online survey was developed in Fall 2013. The E^3 external evaluator then sent an email to former participants from the 2003-2012 E^3 programs, inviting them to respond to the survey questions. The 2013 E^3 teachers were not invited since their program participation had recently concluded. No idenitifying information was requested of teachers during the online survey. A total of 31 teachers responded to the survey. The cohort year for each respondent is presented in Figure 1, and the general content area of the respondents' E^3 lessons is summarized in Figure 2.

Results

Findings From Focus Group Interviews

The E^3 external evaluator analyzed the focus group interviews and categorized the teachers' responses pertaining to long-term benefits of the program as well as challenges in classroom implementation of their E^3 lesson plans. Using a grounded theory approach (Strauss and Corbin, 1994) to categorize the teachers' responses, four themes emerged regarding *long-term benefits*:

1. Improved understanding of engineering,
2. Collaboration/networking with other teachers,
3. Effects on teaching style/approach, and
4. Reenergized when returning to the classroom.

Improved understanding of engineering: The teachers continue to appreciate their increased understanding of engineering. Their responses included: (a) broadened awareness of the different engineering disciplines, (b) better able to assist students with college and career advice, (c) better able to explain the importance of STEM to their students, and (d) better able to promote engineering as a potential career to their students. A representative quote from one of the teachers:

- *"Now I feel like I can talk about engineering and the college experience and at least be a source of information for my students. I can provide guidance even though I am not the guidance counselor."*

Collaboration/networking with other teachers: The teachers enjoy the E^3 network of fellow STEM teachers. They see value in the collaborative relationship developed with other teachers: reconnecting with teachers from their cohort and meeting teachers from other E^3 cohorts. Two representative quotes from the teachers are:

- *". . . networking that we did with other teachers from other places, other sized districts, other types of schools, and the importance of that."*
- *". . . .networking with teachers who teach at different types of schools. . . I think that is very interesting and beneficial to me as an educator."*

Effects on teaching style/approach: Several teachers said that, since their E^3 experience, they try to make their lessons more interesting and creative. Several teachers incorporate the engineering design process into their classroom lessons on a regular basis. Two of the teachers commented:

- *". . . allowed me to teach in a manner that reaches a majority of the students that take my classes. . . .. By changing the manner of inquiry an engineer uses to solve problems, provided a contextual mind set allowing the students to retain the information being taught."*
- *"I have incorporated several engineering projects into my curriculum. Students are learning they can solve problems and think originally, which is quite novel to some of these kids."*

Reenergized when returning to the classroom: Numerous teachers indicated that their E^3 experience invigorated them; they felt reenergized to go back into the classroom. Some said that they were excited to make the classroom more "real world" for their students; others stated that they have newfound confidence to do labs and work with the students. Many teachers felt that opportunities to return to the TAMU campus (e.g. E^3 Workshops, campus events for their high schoolers) also kept them invigorated. One of the teachers commented:

- *"I have many more ideas to motivate students and show how math is applied in the real world such as engineering."*

In terms of *long-term challenges* associated with classroom implementation of their E^3 lesson, the teachers' responses can be categorized as:

- Lack of time,

- Curriculum constraints (scope and sequence),
- Lack of support from school administration, and
- Lack of funds.

Lack of time: Time constraint was the most commonly cited challenge when implementing their E^3 lesson in subsequent academic years. Factors included: (a) over-prescribed curriculum, (b) shorter class periods, and (c) an overly ambitious E^3 project for the allotted timeframe. To combat this problem, several teachers indicated that they had selectively taught "pieces" of their E^3 lesson in subsequent years.

Curriculum constraints (scope and sequence): Increasingly for the core math and science subjects, the curriculum has become more tightly packed. This leaves little time for activities such as those developed during their E^3 experience. With the increased focus on state testing, some of the teachers complained about losing class time due to increased pressure to stay on curricular scope and sequence timetables prescribed by the State.

Lack of support from school administration: Another challenge cited by several teachers was in regard to their school administration. Some teachers were required to get administration approval to conduct their E^3 lesson. Although the principals were aware of teacher participation in E^3 (principal signature required on the E^3 application form), sometimes they were not as receptive in allowing adequate class time for the teachers to implement their E^3 lessons.

Lack of funds: Participants each received a $600 budget to purchase the necessary supplies to implement their E^3 classroom activity. However, several teachers indicated that it was difficult to replicate their E^3 lessons in subsequent academic years due to cost constraints (e.g., cost of consumables, other).

Findings from Long-Term Impact Survey

To assess potential long-term impact on classroom implementation efforts, several questions addressed classroom implementation and the success of increasing the focus on engineering in the classroom. When asked the number of years they have implemented their E^3 lesson (Figure 3), the majority of teachers (n=19) noted 1 or 2 years. Seven teachers (n=7) indicated that they had implemented their E^3 lesson for ^{3} or 4 years since attending the E^3 program. Although a total of 18 respondents had been in the classroom at least ^{3} or 4 years since participating in the program (i.e., teachers from cohorts 2003-2010), only 39% of them (or 7 out of 18) were actually able to implement their lesson that many times. Similarly, 11 teachers (i.e. respondents from cohorts 2003-2007) had been back in the classroom for at least 5 years since participating in the summer program, but only 3 of these teachers (or 27%) were able to implement their engineering-centered activity at least 5 times. These data align with the qualitative findings (i.e. from the focus group interviews) indicating the challenges of implementing this content on a long-term basis.

When asked to rate the success of implementing their E^3 lesson, 27% indicated "very successful", 63% "mostly successful," and 7% "mixed" (data not presented). These findings suggest that if implemented (with time and resources), teachers can experience success with the E^3 lesson in their classrooms.

The teachers were asked to describe the challenges of implementing the E^3 lesson plan into their curriculum. The teachers wrote their responses, and the responses were tallied and reported in Figure 4. The greatest challenge was "time," but other factors (i.e., curricular restrictions, testing/state assessments, cost of materials) were also important. These results align with focus group findings presented previously. Based on these findings, future E^3 programs and other RET programs should work with teachers during their summer research experience to determine how they can assist teachers in dealing with these challenges.

Despite the aforementioned challenges, teachers

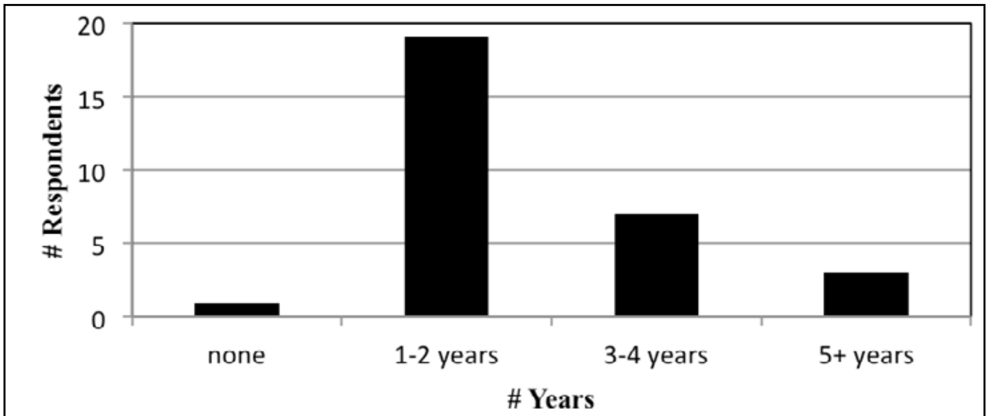

Figure 3: How many years have you been able to implement your E^3 lesson and/or other engineering centered activities into your curriculum?

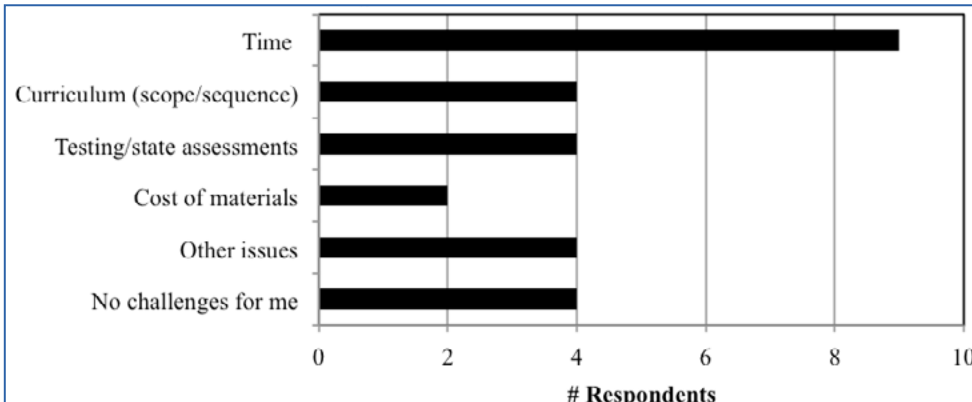

Figure 4: Describe the challenges of implementing your E^3 lesson plan into your curriculum.

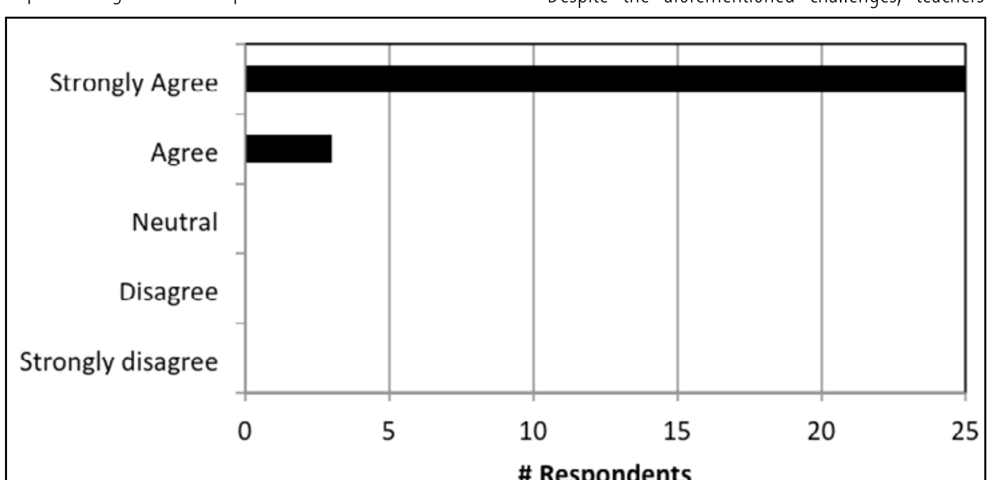

Figure 5: A s a result of attending the E^3 summer experience, I have been better able to promote the field of engineering to my students.

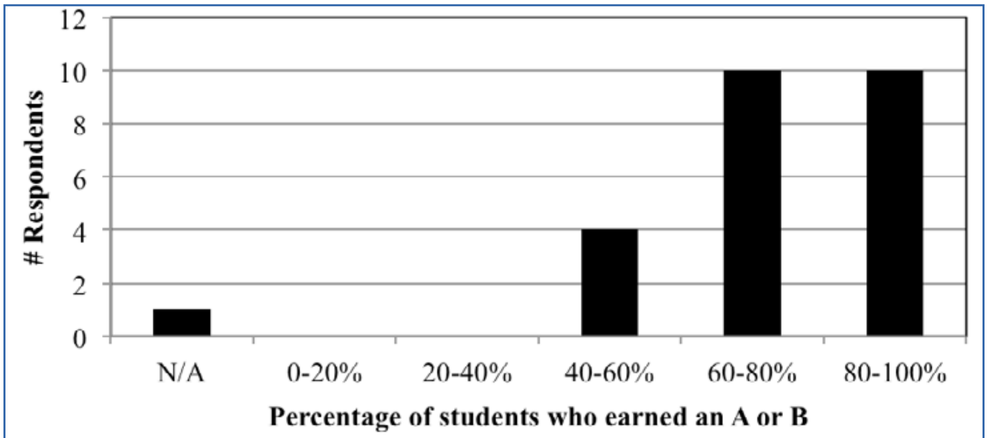

Figure 6: As best you can recall, what percentage of your students mastered the content presented in the E³ lesson (ie., letter grade of "A" or "B")?

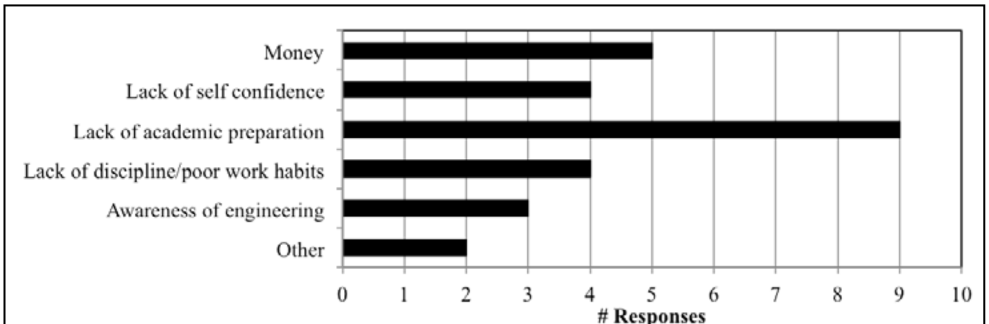

Figure 7: What do you think are the biggest impediments for qualified students (in your school) to study engineering at the postsecondary level?

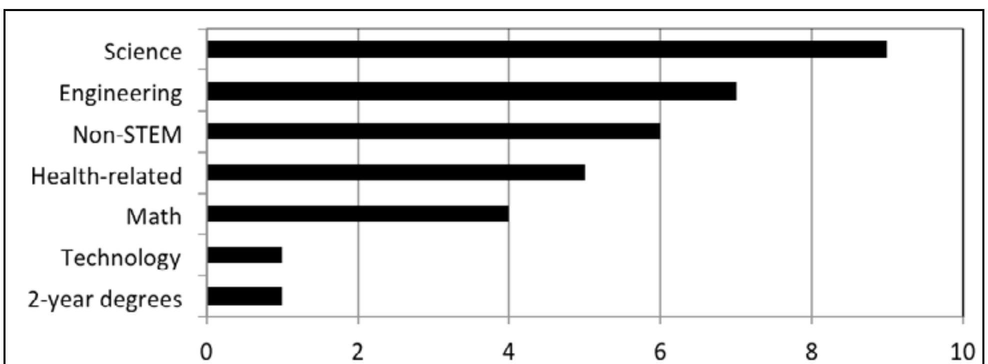

Figure 8: Following your E³ experience (and to the best of your recollection), describe/list the postsecondary academic majors that have been mentioned/discussed to students in your classroom.

were asked if they were able to develop additional engineering materials for use in their classroom. Based on their reporting, 59% were able to develop additional materials to support their E³ lessons, but 34% were not able to do so (data not presented). These findings show promise that teachers are utilizing knowledge from their E³ summer experience to expand the learning experiences of their students.

In post-program surveys administered at the conclusion of each E³ summer program, participants indicated that their knowledge about engineering careers improved substantially by participation in the E³ program, and that they anticipated being better able to promote engineering to their students (Autenrieth et al., 2014). In the current long-term impact study, survey respondents were asked about their ability to promote engineering to their students. Their responses to a Likert scale of options were tallied and reported in Figure 5. The results suggest that former participants of the E³ program continue to feel strongly about their ability to promote engineering to their students even though a period of time has passed since their E³ experience. These feelings align with the focus group findings presented previously.

Figure 6 addresses the question, "What percentage of your students mastered the content presented in the E³ lesson (i.e., letter grade of A or B)." Of the teachers responding (n=25), 10 teachers noted 60-80% and 10 teachers noted 80-100% of their students mastered the content with a letter grade of A or B. These findings highlight that when students are exposed to engineering-related content that they can be successful in learning it. When asked the biggest impediments for their (qualified) students to study engineering, the teachers provided written responses, which were tallied and summarized in Figure 7. "Lack of academic preparation" was the most frequently reported impediment, followed by factors of money to attend college, lack of self-confidence, lack of discipline/poor work habits, lack of awareness of engineering. These findings indicate teachers' concerns that many students who have the potential to pursue engineering may not be prepared for the rigors of this academic major.

When asked to indicate the postsecondary academic majors discussed with their students, the teachers provided written responses, which were tallied and reported in Figure 8. Their responses indicate that "science" was discussed most frequently, followed by "engineering." Others in rank order were: (a) non-STEM, (b) health-related, (c) math, (d) technology, and (e) two-year degrees.

Discussion

The mission of the E³ program is to excite and inform teachers about the engineering field so that they can inform and encourage their students to consider a career in engineering. As such, assessing long-term program impact should focus on the participants as well as the students they come in contact with in the classroom.

Addressing Research Question 1 (long-term program impact on participants)

Findings from the focus group interviews and the online survey indicate that the teachers' improved understanding of the field of engineering stayed with them through the years. Added benefits for the teachers included positive effects on their teaching style, being reenergized when returning to the classroom, and personal professional achievements that they could link to their E³ experience. The findings also suggest that there were challenges for many of the teachers when trying to implement their E³-developed classroom lesson plans in subsequent academic years. These challenges included lack of time, curricular constraints (scope and sequence), lack of funds for materials, and poor support from campus administration.

During the ten years of the program that is being reported, the E³ team was made aware of a progressive increase in difficulties encountered by the teachers with the implementation of their E³ lessons largely due to a decrease in curriculum flexibility. While other venues exist to expose students to engineering that are valuable opportunities for students who can participate in them (e.g., summer camps and after-school programs), the numbers of students impacted is less than if a teacher is able to impact his/her classroom students over the course of his/her career. However, the E3 team recognizes that it is important to provide these types of experiential activities and broadened awareness of engineering to as many students as possible. Teaching components of their E3 classroom lesson was one strategy that some E3 teachers used to remediate the "lack of time" issue.

Addressing Research Question 2 (Impact On Their Students With Regards To The Field Of Engineering)

In the focus group interviews and the online survey, the teachers indicated that they continue to promote the field of engineering to their students. Moreover, many of the teachers had more confidence to discuss college and career plans with their students as a result of their E3 experience. The vast majority of the respondents indicated that the initial classroom implementation of their E3 lesson was successful, and approximately 67% of the respondents stated that they were able to develop additional engineering-related materials for their classroom lessons. However, many of them indicated that it was difficult to find the resources (time, funds, etc.) to implement their E3 lessons in subsequent academic years.

When asked their opinions regarding impediments for their students for considering an engineering major/career, the most commonly cited impediments were: lack of academic preparation, followed by cost, lack of self-confidence, poor work habits, and lack of awareness of engineering.

Student Survey to Assess E3 Program Impact

Another important study conducted to assess E3 program impact was implemented via a survey of the E3 participants' students. To gauge student awareness of engineering, participants from five E3 cohorts (2009-2013) were required to administer a short survey (pre- and post-E3 lesson implementation). Over 2,000 students responded to the survey and preliminary findings suggest that student awareness of engineering increased as did their interest in pursuing an engineering degree in college after classroom implementation of the E3 activity. A manuscript is currently in preparation for publication in a scholarly journal.

Conclusions and Recommendations

The National Science Board (2010) and the National Research Council (2009) recognize the need to expose K-12 students to engineering-related classroom activities and engineering education efforts are gaining momentum in teacher training and professional development (Klein-Gardner et al., 2012; Marshall, 2012).

The findings of this long-term impact study indicate that the E3 program has been successful in educating teachers about the engineering field and careers in engineering, and teachers were better able to promote engineering to their students. However, the teachers had challenges while implementing their E3-developed classroom lessons due to various factors, with lack of time being the most commonly cited constraint. As such, the following recommendations are for the continuation of the E3 program, but are relevant for other RET programs currently being funded:

Future of the E3 Program

1. We recommend that this program work to provide high school STEM teachers with resources to sustain curricular implementation for longer than 1-2 years.
2. We recommend that teachers are provided with necessary strategies to work with their school districts to get additional time, space in the curricular sequence and buy-in from their school administrators for engineering exposure to students given the limited flexibility due to the focus on testing.
3. We recommend stronger support from this program to assist teachers in developing instructional materials to adequately impact the learning experiences for high school students based on the skills learned in the E3 program.
4. We recommend that this program continue to provide teacher participants with the most current information on academic majors and career opportunities in the field of engineering. This will allow teachers to provide this current information to high school students, particularly those from underrepresented groups.

Although NSF funding for the E3 program concluded in August 2013, the TAMU College of Engineering has continued to offer this summer program to Texas high school science and mathematics teachers using other sources of financial support.

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