The Enrichment Experiences in Engineering (E3)

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The Enrichment Experiences in Engineering (E^3) 
Summer Teacher Program: Analysis of Post-Program Surveys

Abstract

Since 2002, the Enrichment Experiences in Engineering (E^3) summer teacher program has provided engineering research opportunities to Texas public high school teachers. Through funding by the National Science Foundation’s Research Experiences for Teachers (RET) program, E^3 has hosted a total of 150 teachers. Most of the teachers have come from schools with high minority student populations (average 83% Hispanic and/or African American; average 69% economically-disadvantaged). Although the program has evolved over the years due to ongoing formative evaluation efforts, the E^3 program goal “to involve teachers in engineering research” has remained the same as have the three core objectives: (1) provide engineering research experiences and enhance understanding of the nature of engineering; (2) scaffold teacher development of inquiry-based engineering classroom activities; and (3) improve teacher (and indirectly their students) knowledge about careers in engineering.

The E^3 program is designed to bring high school science and mathematics teachers to the Texas A&M University campus for a four-week summer residential experience where the teachers are mentored by engineering faculty. During the program, teachers are involved in: (1) hands-on participation with current engineering research, (2) activities to broaden their awareness of engineering career opportunities for their students, and (3) development of an engineering project for implementation in their high school classroom.

Although the E^3 program is not a research project, the E^3 program’s goal and core objectives can be linked to anticipated outcomes. As part of the program’s formative and summative evaluation, anonymous online surveys were administered to participants in two E^3 summer programs using the pre- and post-program survey format, and participants were asked to respond to survey statements using a Likert-type scale of responses. The E^3 leadership team noted inconsistencies in some of the survey results with the teachers’ written (and verbal) comments; therefore the team investigated the apparent contradictions. Possible explanations included (a) pre-program survey response overestimation and concomitant response shift bias for several of the survey questions, and/or (b) teachers’ belief that something is true without a factual basis for that belief. Although there were several design approaches to consider, the E^3 team determined that the retrospective post-then-pre survey design was the best fit for the program and therefore restructured the affected questions for subsequent post-program surveys. As such, the revised surveys were administered to participants in the subsequent E^3 summer programs.

Major survey findings indicated that the E^3 participants experienced substantial changes in the following areas: (1) improved understanding of the engineering discipline; (2) heightened awareness of the breadth of engineering careers; and (3) greater familiarity regarding important skills and attributes to be a successful engineer. As a “lessons learned” note to administrators of teacher research experience programs: When selecting an experimental design for participant surveys, program administrators should investigate the options, weigh the advantages and disadvantages, and then select the option that best fits the needs and constraints of their program.
Introduction

Numerous reports have stressed the demand for more STEM graduates to satisfy increasing STEM workforce needs\(^1\)\(^-\)\(^7\). Overall, the U.S. has experienced long-term declines in engineering enrollments\(^5\), but anticipates a 10% job growth in the engineering disciplines over the next several years\(^8\)\(^-\)\(^9\). 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. And despite efforts across the country to broaden participation of students underrepresented in engineering majors (i.e., women, Hispanics, African Americans)\(^10\)\(^-\)\(^13\), both the enrollment numbers and engineering degrees awarded to these underrepresented groups is well below parity\(^14\)\(^-\)\(^16\). With the changing demographics of Texas\(^17\) and the country\(^18\), it is essential to recruit from underrepresented minority groups, as well as women, to help satisfy projected engineering workforce needs. And while it is important to increase the engineering workforce numbers, increasing the diversity of the engineering workforce enhances the development of the most effective responses of engineering solutions to societal needs. As explained by William Wulf, former president of the National Academy of Engineering, engineering is a very creative profession and an individual’s expression of creativity is a function of his/her life experiences. Wulf stated, “Without diversity, the life experiences we bring to an engineering problem are limited. As a consequence, we may not find the best engineering solution. We may not find the elegant engineering solution\(^19\).”

Diversity allows for flexibility within a company, which is important to remain competitive both domestically and globally. Minority engineers bring a different cultural background (and often a second language for Hispanic engineers) which provides unique contributions to engineering solutions. Engineers who mirror the customer can offer a critical perspective; Ford Motor Company assembled a development team of 30 female engineers to design the (1999) Ford Windstar minivan for their target market: women with children. Similarly, when designing a car to meet the needs of female drivers, Volvo employed an all-female design team to make all the development decisions for the YCC (Your Concept Car).

For more students to identify engineering as an educational option, the engineering profession needs K-12 teachers who understand what engineers do as the problem solvers for society. Studies have shown that teachers can have significant influence when high school students are making career choices, particularly when selecting STEM careers\(^20\); and their guidance can be particularly helpful for minority students\(^21\)\(^-\)\(^25\). Although significant funds are expended each year to improve public understanding of engineering, research indicates that K-12 teachers and students typically have little understanding of the profession\(^26\)\(^-\)\(^30\). Because “front line” impact is made by teachers, educating them about engineering and deepening their awareness of engineering careers can inspire students to pursue the study of engineering and other STEM subjects.

Illustrating concepts in math and science through engineering examples can provide tangible applications that enhance student understanding. Teachers need to first develop their own understanding of engineering, create linkages between the subject content they teach to develop lessons that apply these concepts to solve engineering problems. Engineers solve problems by applying math and science principles through the engineering design process. Being able to
relate math and science concepts to engineering solutions that are relevant to students demonstrates the importance of mastering these skills.

Funded by the NSF RET program, the Enrichment Experiences in Engineering (E³) for Teachers Summer Program has provided an important link between secondary schools and the university. Hosted by the College of Engineering (COE) at Texas A&M University (TAMU), E³ has been 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.

Program Description

Overview

Although the E³ program has evolved over the years, the core program objectives have remained essentially the same: (1) provide engineering research experiences to teachers and enhance their understanding of the nature of engineering; (2) scaffold teacher development of authentic inquiry-based engineering classroom activities; and (3) improve teachers’ (and indirectly their students’) knowledge about careers in engineering. A brief summary of the program objectives and associated activities is outlined as follows. Additional program details can be found elsewhere.

- **Objective 1 activities**: Teachers are paired and then matched with an engineering faculty mentor. The mentor assists the teachers in understanding the current status of emerging technologies and engineering research, and provides informal instruction in research methodology and science theory appropriate to the teacher’s research experience.

- **Objective 2 activities**: During the four-week summer program, each teacher prepares hands-on engineering-related instructional materials to integrate into their classroom curriculum. Support is provided by engineering education specialists and others; instruction on the engineering design process is provided.

- **Objective 3 activities**: Field trips to high-tech industry plants allow the teachers to see firsthand what engineers do in industry. Other opportunities to further expose teachers to various engineering fields include weekly dinners in which an engineering faculty member discusses his/her research area (e.g. alternative energy sources, materials science, tissue engineering, cyber security, and others).

Over the 11 years of the E³ program (2003-2013 E³ summer cohorts; 150 teachers total), the participant demographics collectively were 48% White, 27% Hispanic, 15% African American, 9% Other. Eighty (80) participants were female and seventy (70) were male. Most E³ teachers were from schools with high minority student populations (average 83% Hispanic and/or African American; average 69% economically-disadvantaged).

Previous E³ program evaluation

*Summative evaluation* of the early years of the E³ program focused primarily on qualitative questions to measure program objectives and anticipated outcomes; a focus group session and responses to an online survey provided additional insights. *Formative evaluation* of the E³
program has led to several program modifications, both large and small. Based on participant suggestions, some of the most significant improvements have included the following: (1) an annual E³ workshop is hosted during the academic year to support the E³ teacher network and maintain ties with the COE; (2) two E³ master teachers (former E³ participants) come to campus to work with the participants as they develop their E³ classroom project; (3) teachers are required to create an E³ poster for their classroom to further promote engineering to their students; (4) formal instruction on the engineering design process has been incorporated into the summer program so that teachers better understand the engineering approach to problem solving; and (5) low-key ad hoc social activities for the entire E³ cohort are encouraged to promote bonding within the cohort.

Methods

When co-author Dr. C. Lewis joined the E³ team as an external evaluator in 2007, he developed an anonymous on-line post-program survey to be administered to all future E³ cohorts. It included both summative- and formative-type statements/questions; providing a Likert-type scale of response options (i.e. strongly agree, agree, neutral, disagree, strongly disagree), as well as opportunities to augment their responses with additional comments/suggestions. Aside from the teachers’ augmented comments on the survey, it was difficult to know if any change occurred since there was no-pre-test for comparison. As a result, a pre-program survey was introduced in 2009 for comparative purposes to the post-program survey. Specifically, the teachers responded to pre-program survey questions on Day 1 of the program, subsequently participated in the four-week summer program, and then responded to the same questions in the post-program survey at the conclusion of the program.

For the 2009 and 2010 E³ cohorts, pre-post surveys were administered. After compiling and plotting the data from these survey responses, the E³ team noticed inconsistencies with the quantitative data (i.e., pre- and post-program survey responses) as compared to the written (and verbal) comments (i.e., qualitative data) from the teachers. The teachers’ comments led the E³ team to believe that the program had a pronounced impact on their understanding of engineering, engineering careers, and characteristics of engineers. However, the pre- versus post- survey responses on many of the survey questions contradicted those impressions.

The E³ team investigated the use of another survey design to more accurately reflect the changes in the teachers’ self-reported understanding of engineering. Since all experimental designs have advantages and disadvantages, program administrators need to review the relevant options and determine which survey approach is the best fit for their program. Shadish et al.3 outline several quasi-experiment designs to consider when a control group is lacking (which was the case for the E³ program evaluation).

Pre-post survey design

The one-group pretest-post-test design can be appropriate when attempting to change a characteristic that is resistant to change35. The pre-post design is a commonly accepted standard in the engineering education community and it has its advantages. However, there can be concerns of internal validity, and if the intervention is of short duration, there can be a test/retest
validity threat. Another possible concern with the pre-post survey design is response shift bias.

Response shift and response shift bias

“Response shift” occurs when a participant uses a different frame of understanding about a question between the pre and post periods, i.e., when a participant answers a question from a different mindset on the post-program survey as opposed to his/her mindset when addressing the question during the pre-program survey. It can create a problem when assessing self-reported change, particularly in educational program surveys because these types of programs are designed to improve the participants’ knowledge, skills, attitudes, to name a few. This can lead to a response shift bias. Actual changes in knowledge, skills, behavior, etc. can be masked due to the respondents’ overestimation of their pre-program knowledge, which can also lead to underestimation of the program’s effectiveness. For example, a self-report on the participants’ understanding of engineering careers may be over-reported on the pre-program survey if the teachers do not fully realize what they don’t know about engineering careers. However, some belief questions may not be subject to bias; the respondents may know that a statement is true, but they do not have the experience to understand why the statement is true.

Retrospective post-then-pre survey design

The E³ team decided on the retrospective post-then-pre design as an alternative survey format for subsequent program evaluation. The retrospective post-then-pre design was proposed in the late 1970’s as a way to minimize/eliminate response shift bias in self-reporting pre-post surveys. In the retrospective post-then-pre design, both before and after information is collected at program conclusion. The participant is asked to rate his/her current knowledge/skills/attitude behavior as a result of the program, and is also asked to reflect back and rate that same knowledge before participating in the program. Since the survey is administered at the program conclusion, their new understanding of program content can help them better assess their pre-program knowledge. The retrospective post-then-pre design has several advantages. It takes less time because the survey is given only one time (i.e. at the end of the program). It avoids pretest sensitivity (test-retest validity threat) and response shift bias that results from pretest overestimation or underestimation; and compared to the pre-post design, the retrospective post-then-pre results are typically more consistent with participant interview data. However, disadvantages include “recall period” (i.e., how accurately the respondent remembers over time), and self-reporting bias (i.e., when the respondent answers the way he/she thinks the evaluator wants them to respond).

The E³ external evaluator restructured the questions using the retrospective post-then-pre format, and the surveys administered to the 2011, 2012, and 2013 E³ cohorts included these restructured questions. The teachers’ responses to these questions serve as a focal point of this paper.

Data analysis calculations

As outlined previously, the teachers from the 2009 and 2010 E³ cohorts (all 23 teachers responded) were evaluated using the pre-post survey format by responding to two surveys (i.e.
the pre-program survey and the post-program survey). The teachers from the 2011, 2012, and 2013 cohorts (37 responded out of 42 teachers surveyed) were evaluated using the retrospective post-then-pre survey format; they responded to one survey at the program conclusion and providing two responses that reflected their pre-program and post-program thoughts.

For data analysis purposes, each response type was assigned a numeric value: strongly agree (5 points), agree (4 points), neutral (3 points), disagree (2 points), strongly disagree (1 point). Using the assigned numeric values, the mean and standard deviation were determined for questions in both the pre-post surveys as well as in the retrospective post-then-pre surveys. In addition, percent change calculations were determined for select questions.

**Percent change**: To compare the pre and post responses, a percent change was calculated for each survey question using the following equation,

\[
\text{Percent Change} \ (\%) = \left( \frac{\text{Postprogram composite number}}{\text{Preprogram composite number}} - 1.0 \right) \times 100
\]

where the composite number was determined by multiplying each teacher’s response by the respective numeric value and summing the resulting values.

**Results**

The evaluation results and program outcomes are organized as they relate to the three core program objectives, which include providing engineering research experiences; enhancing teacher understanding of the engineering field; supporting teachers as they develop an engineering-related hands-on classroom activity; broadening the teachers’ awareness of engineering careers; and increasing their students’ awareness of engineering careers. The majority of the results presented in this paper are based on participant responses from the pre-post surveys and the retrospective post-then-pre surveys.

**Core Objective #1**: Provide engineering research experiences and enhance understanding of the nature of engineering.

Results and outcomes for Objective #1 are divided into two sub-sections, as they relate to (a) providing engineering research experiences and (b) enhancing teacher understanding of engineering.

**Provide engineering research experiences**

During the \(E^3\) summer program, the teachers were given the opportunity to participate in engineering research, an activity that accounted for approximately 40% of the four-week program. Over the years, faculty members from several TAMU engineering (and computer science) departments served as \(E^3\) faculty mentors; the engineering departments include aerospace, biological & agricultural, biomedical, chemical, civil, computer, electrical, industrial, mechanical, and nuclear (Table 1). Over half of the \(E^3\) faculty mentors were current (or previous) NSF CAREER awardees, and \(E^3\) served as an important part of their required educational/outreach plan.
Table 1: Engineering Faculty Mentors for the E³ RET Program

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<td>2006</td>
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<td>2008</td>
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<td>1</td>
<td>2</td>
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<td>2009</td>
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<td>1</td>
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<td>2010</td>
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<td>1</td>
<td>2</td>
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<td>2011</td>
<td>2</td>
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<td>3</td>
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<td>2012</td>
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<td>2013</td>
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<td>1</td>
<td>1</td>
<td>3</td>
<td>3</td>
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</tr>
</tbody>
</table>

*2003 information unavailable

The teachers overwhelmingly reported positive experiences from the research time with the faculty. The post-program surveys for cohorts 2011-2013 included the following statement: “The research experience in my faculty mentor’s laboratory enhanced my summer experience.” Of the 37 teachers responding in the post-program survey, 78% “strongly agreed” and 19% “agreed” with this statement (mean 4.76 ± 0.49). The quotes below typify the sentiments of the majority of the teachers:

- “Without the research component, this would be another extended workshop on developing inquiry-based lesson plans. Getting to see the inner-working of a research lab and participating as a student added a very neat perspective on the lesson I was developing.”
- “The hands-on experience that I obtained, gave me an added skill set that will make me more effective in the high school Biology lab.”
- “This was like a dream come true for me. I have always wanted to be involved in this kind of current, active research.”

**Enhanced understanding of engineering**

To address how the program enhanced the teachers’ understanding of engineering, participant responses to eight selected survey questions were compiled and analyzed. These questions were designed to ascertain the teachers’ understanding of required and/or desirable characteristics to be a successful engineer.

For the 2009-2010 E³ cohorts (23 respondents), the eight statements were presented to the teachers using the pre-post survey format; the mean scores are presented pictorially in Figure 1. For subsequent E³ cohorts (2011-2013; 37 respondents), only a post-program survey was administered and the eight questions were re-formatted using the retrospective post-then-pre design. The mean scores are presented pictorially in Figure 2. When comparing the visual representations of the mean scores in Figures 1 and 2, it appears that there was a response shift bias in the pre-post survey questions, except for Statement 1 (and possibly Statements 2 and 3).
Figure 1. Mean Scores for Pre-Post Data

(Pre: — Post: — )

<table>
<thead>
<tr>
<th>Statement</th>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Knowledge of mathematics is important for a career in engineering.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>2. Knowledge of science is important for a career in engineering.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>3. Problem solving skills are important for a career in engineering.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>4. Creativity is an important asset for a career in engineering</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>5. Participating in teams is a component of an engineering career.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>6. Engineers have a desire to contribute to society.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>7. Engineering is an exciting career.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>8. Engineers tend to work alone.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
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</tbody>
</table>

Figure 2. Mean Scores for Retrospective Post-Then-Pre Data

(Pre: — Post: — )

<table>
<thead>
<tr>
<th>Statement</th>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Knowledge of mathematics is important for a career in engineering.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>2. Knowledge of science is important for a career in engineering.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>3. Problem solving skills are important for a career in engineering.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>4. Creativity is an important asset for a career in engineering</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>5. Participating in teams is a component of an engineering career.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>6. Engineers have a desire to contribute to society.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>7. Engineering is an exciting career.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
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<tr>
<td>8. Engineers tend to work alone.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>
To quantify the comparisons between pre and post responses, a *percent change* for each question was calculated (Table 2), where the percent change values quantify the shift towards the “agreement” end of the Likert scale. The left-hand column of values in Table 2 provides the percent change in survey responses for the *pre-post* surveys and the right-hand column of values provides the percent change for the *retrospective post-then-pre* surveys.

**Table 2. Percent Change When Comparing Pre and Post Participant Responses**

<table>
<thead>
<tr>
<th>Statement</th>
<th>*Pre and Post Surveys (% change)</th>
<th>**Retrospective Post-then-Pre Surveys (% change)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Knowledge of mathematics is important for a career in engineering.</td>
<td>5%</td>
<td>3%</td>
</tr>
<tr>
<td>2. Knowledge of science is important for a career in engineering.</td>
<td>3%</td>
<td>14%</td>
</tr>
<tr>
<td>3. Problem solving skills are important for a career in engineering.</td>
<td>2%</td>
<td>14%</td>
</tr>
<tr>
<td>4. Creativity is an important asset for a career in engineering.</td>
<td>4%</td>
<td>36%</td>
</tr>
<tr>
<td>5. Participating in teams is a component of an engineering career.</td>
<td>4%</td>
<td>37%</td>
</tr>
<tr>
<td>6. Engineers have a desire to contribute to society.</td>
<td>9%</td>
<td>38%</td>
</tr>
<tr>
<td>7. Engineering is an exciting career.</td>
<td>10%</td>
<td>44%</td>
</tr>
<tr>
<td>8. Engineers tend to work alone.</td>
<td>-29%</td>
<td>-53%</td>
</tr>
</tbody>
</table>

*Cohorts 2009-2010 (23 teachers responding) **Cohorts 2011-2013 (37 teachers responding)*

For Statement 1, the percent change for the *retrospective post-then-pre* surveys responses was similar to the percent change for the *pre-post* survey responses (i.e. 3% vs. 5%, respectively). This suggests that high school STEM teachers already understood that strong math skills are important for engineers, which aligns with previous findings by Baker et al.\(^{30}\). Although the E\(^3\) experience did not provide much in the way of raised awareness regarding this attribute, several teachers commented that the E\(^3\) experience provided examples of how various math skills are used in engineering applications, which is useful information to share with their students.

For Statement 2, the comparisons of percent change (14% vs 3%) suggest a couple of possible explanations. Although there may have been some pre-test sensitivity for the teachers responding in the *pre-post* surveys, another explanation surfaces with a closer look at the *retrospective post-then-pre* survey data. Most likely, the teachers came into the E\(^3\) program with the belief that science knowledge was important for engineers, which agrees with other research findings\(^{30}\). The teachers were not overstating their belief, but they did not have any factual basis to support it. The E\(^3\) experience provided some framework to support this belief, as indicated by the 14% change in the *retrospective post-then-pre* survey responses. A similar conclusion could be drawn for Statement 3 regarding the teachers’ understanding that problem-solving skills are important for a career in engineering.

The percent change for Statements 4-7 provide evidence that there was some pre-program response overestimation (i.e., pre-test sensitivity) and concomitant response shift bias for the cohorts taking the *pre-post* surveys. The pre-program responses suggest that the teachers entered the program with a high level of awareness of the engineering attributes, which counters other studies indicating that K-12 teachers are generally unfamiliar about engineering, characteristics of engineers, and what engineers do\(^{26-27,30}\). Moreover, the percent change for these questions
ranged from 4% to 10%, suggesting that the teachers experienced little change during the course of the program, which is inconsistent with written (and verbal) comments made by the teachers. The responses to the reformatted questions in the retrospective post-then-pre survey for subsequent cohorts reflect the teachers’ raised awareness of these engineering attributes due to participation in the E3 program; the percent changes were much higher (ranging from 36% to 44%).

For Statement 8, although the teachers were somewhat neutral in their pre-program responses as to whether engineers tend to work alone, the percent changes for the two survey types (i.e., -29% and -53%) indicated that their post-program responses shifted toward disagreement with this statement. In other words, because of their participation in the E3 program the teachers realized that engineers do not tend to work alone.

To analyze these data for statistical significance, the standard deviations were calculated (Table 3). For Statements 5-7, the pre and post responses for the Retrospective Post-Then-Pre surveys were deemed statistically significant; there was no overlap in the standard deviations associated with the two mean scores.

Table 3. Mean ± Standard Deviation for Pre and Post Participant Responses

<table>
<thead>
<tr>
<th>Statement</th>
<th>Pre-Post</th>
<th>Retrospective Post-Then-Pre</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Knowledge of mathematics is important for a career in engineering.</td>
<td>4.65±0.49</td>
<td>4.87±0.34 4.76±0.49 4.92±0.28</td>
</tr>
<tr>
<td>2. Knowledge of science is important for a career in engineering.</td>
<td>4.61±0.50</td>
<td>4.74±0.45 4.33±0.59 4.86±0.35</td>
</tr>
<tr>
<td>3. Problem solving skills are important for a career in engineering.</td>
<td>4.74±0.45</td>
<td>4.83±0.39 4.32±0.71 4.94±0.23</td>
</tr>
<tr>
<td>4. Creativity is an important asset for a career in engineering.</td>
<td>4.57±0.59</td>
<td>4.74±0.45 3.46±1.04 4.70±0.62</td>
</tr>
<tr>
<td>5. Participating in teams is a component of an engineering career.</td>
<td>4.48±0.51</td>
<td>4.65±0.71 3.65±0.89 4.92±0.28</td>
</tr>
<tr>
<td>6. Engineers have a desire to contribute to society.</td>
<td>4.34±0.65</td>
<td>4.61±0.89 3.46±0.87 4.76±0.43</td>
</tr>
<tr>
<td>7. Engineering is an exciting career.</td>
<td>4.22±0.67</td>
<td>4.65±0.49 3.35±0.75 4.81±0.40</td>
</tr>
<tr>
<td>8. Engineers tend to work alone.</td>
<td>2.26±0.69</td>
<td>1.61±0.66 2.92±1.03 1.38±0.64</td>
</tr>
</tbody>
</table>

Another survey question related to enhanced understanding of engineering was rephrased, but not re-structured in the retrospective post-then-pre format. Cohorts 2009 and 2010 responded to the statement, I have some engineering knowledge” in the pre-post format. The pre and post mean scores were 3.30 (±1.06) and 4.17 (±0.49), respectively. For Cohorts 2011-2013, the post-program survey question was rephrased: “Compared to what I knew before the E3 experience, I now have greater knowledge of engineering as an academic discipline.” This statement requested only a post-program response, and the mean score was 4.73 (±0.51).
The post-program comments below provide the essence of what many E³ participants took away from the program regarding engineering and engineers:

- “Solving society's problems is at the heart of Engineering.”
- “Engineers take what we have and make it better. They push the limits.”
- “There is so much to choose from and so many ways to make a difference in the world.”

Core Objective #2: Scaffold teacher development of inquiry-based engineering classroom activities.

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. Requiring minimal changes in curriculum structure, the ad hoc infusion of engineering ideas and activities into existing mathematics, science or technology curriculum is regarded as the most direct and least complicated option. The E³ program models the ad hoc infusion strategy by requiring participating teachers to develop an engineering-related inquiry-based activity for implementation in their high school classroom.

During the E³ summer program, numerous sessions on integrating the knowledge/research experience into classroom lesson plans occurred and participating teachers received support from engineering education practitioners as well as the E³ master teachers. The teachers were encouraged to develop an inquiry-based classroom activity that was representative of the way engineers approach problem solving. As the teachers endeavored to fashion their lesson plan to incorporate aspects of the engineering design process, instruction provided on the engineering design process during the E³ program was particularly helpful. The teachers understand the scientific method process, but the engineering design process is unfamiliar to most of them. As the E³ program matured, feedback from participating teachers inspired the E³ team to incorporate more structured lectures on the engineering design process in subsequent E³ programs. The teachers learned about the history of engineering, what an engineering project is, examples of engineering feats (and disasters), and detailed information on each step of the engineering design process. During the instruction time, the teachers had opportunities to participate in short exercises that demonstrated various aspects of the design process. When queried if these lectures enhanced their understanding of the engineering design process, 73% of survey respondents “strongly agreed” and 26% “agreed” (mean 4.72 ±0.46). As one teacher stated: “Mr. Chinn’s lectures were very effective in helping me understand the engineering design process. Many of his activities are also on the level where I can adapt them to use in my classroom which is very cool.”

During the 11 years of the program, all participants developed an engineering-related activity for their classroom, and the majority of them implemented their E³ lesson plan during the subsequent academic year. Although complete records are not available for the 2003-2007 cohorts, 81% of the teachers from the 2008-2012 cohorts implemented their E³ lesson/activity in their classroom. For those teachers who were not able to conduct their E³ lesson, it was typically due to circumstances beyond their control (e.g., personal medical issues; school administrative barriers; scope and sequence issues; other). Teachers in the 2013 E³ cohort are in the process of implementing their E³ lesson during the 2013-14 academic year.
Core Objective #3: Improve teacher (and indirectly their students) knowledge about careers in engineering.

Outcomes for Objective #3 were determined by (1) measuring how teachers perceived that their knowledge about engineering careers improved as a result of the E³ program, and (2) how they perceived their ability to convey that knowledge to their students.

Enhanced teacher understanding of engineering careers

One survey question specifically addressed enhanced awareness of engineering careers as a result of the E³ program. In the pre-post surveys (cohorts 2009-10), the teachers were asked to respond to the following statement, “I have an awareness of the breadth of engineering careers.” The mean scores were 3.56 ± 0.99 (pre) and 4.61 ± 0.50 (post), which represented a 29% percent change in their collective responses. Although the percent change was fairly substantial, it is possible that there was some preprogram overestimation and concomitant response shift bias. For cohorts 2011-2013, the question was rephrased to read as follows: Compared to what I knew before the E³ experience, I now have a greater awareness of the breadth of engineering careers.” The teachers were asked to provide only a post-program response; the mean score was 4.89 ± 0.31. The teachers strongly felt that their knowledge about engineering careers improved substantially by participation in the E³ program.

The two primary program activities designed to broaden the teachers’ awareness of engineering and engineering careers included industry field trips and weekly dinner speakers. Using the Likert scale, the teachers were asked to respond to seven individual questions regarding the three field trips and the four program dinner speakers and whether those activities enhanced their E³ summer experience. A total of 78 teachers responded (94% of the teachers in the 2008-2013 cohorts) to the surveys. Regarding the field trips, 61% strongly agreed and 32% agreed that the trips enhanced their E³ experience (mean score 4.54 ± 0.64). Regarding the dinner speakers, 59% strongly agreed and 34% agreed that the speaker presentations enhanced their E³ experience (mean score 4.50 ± 0.66).

Enhanced student understanding of engineering and engineering careers

Participating teachers were also asked to assess their ability to share their knowledge about engineering to their students by responding to the following question: As a result of this E³ summer experience, I anticipate being better able to promote engineering to my students.” In the pre-post surveys, the teachers’ responses yielded mean scores of 4.91 ± 0.29 (pre) and 4.87 ± 0.34 (post), which represents a -1% percent change. Certainly, pre-program response overestimation occurred. However, since the E³ program was advertised as providing teachers with the needed information to increase their students understanding and awareness of engineering and engineering careers, it is reasonable to assume that the teachers came into the E³ program with these expectations. For the other cohorts responding to only a post-program survey (i.e., cohorts 2008, 2011-13), the mean score was also 4.91 (±0.28). The following post-program comment is representative of the views of many of the E³ participants: “I now have a plethora of information about the fields of engineering and the blending of the fields so that I can
speak with confidence to my students about pursuing engineering. My knowledge base was sorely lacking and I couldn't find satisfactory information to give me the confidence I required to encourage my students to consider engineering. Now I feel enough confidence to challenge them if they show an aptitude for engineering but are not considering it as a course of study.”

Conclusions

Based on the survey findings presented in this paper, the teachers indicated that their participation in the E³ program was beneficial in a variety of ways. The main findings include:

1. The teachers indicated that they have a better understanding of the characteristics of engineers and what they do.
2. Participation in engineering research was a positive experience for the teachers.
3. The instruction on the engineering design process was valuable to the teachers as they developed their engineering-based classroom lesson plans.
4. All participating teachers developed an engineering-based lesson, and the vast majority of them were able to implement the lesson in their classroom.
5. The activities and experiences during the E³ program broadened the teachers’ awareness of engineering careers.
6. The teachers felt that the E³ program armed them with information and knowledge to promote the field of engineering to their students.

A “lesson learned” for the E³ leadership team is in regards to survey design selection. In the case of the E³ program, the retrospective-post-then-pre survey findings were more consistent with the written (and verbal) teacher comments from the teachers than the pre-post survey findings.

When selecting an experimental design for participant surveys, we recommend that program administrators investigate the options, weigh the advantages and disadvantages, and then select the option that best fits the needs and constraints of their program.

After 11 years as an NSF RET Site program, E³ matured into a highly regarded and successful opportunity for high school STEM teachers, engineering faculty, and indirectly, high school students. “Teaching teachers” is an efficient approach to reach large numbers of students, and can serve as an effective way of providing engineering career exposure to underserved minority student populations who typically do not have other ways to learn about engineering. Collectively, the 150 teachers who have participated in the E³ program have promoted engineering to their students, who are mostly from schools with high-minority low-income student populations (average 83% Hispanic and/or African American and 69% economically-disadvantaged). By sharing stories about their E³ experience, conducting their E³ lessons in the classroom, and providing information about engineering careers, the teachers have exposed thousands of students to the field of engineering.

Although the State of Texas has approved several engineering-related high school courses, it is up to individual school districts to offer the courses, and there can be challenges associated with course additions (e.g., finding certified teachers, limited financial resources, etc.). Bringing engineering into the K-12 classroom with stand-alone course offerings should be complemented with ad hoc infusion opportunities such as those provided by E³ teachers. We need informed
teachers to serve as “champions for engineering” and encourage their students to consider a career in engineering.

Through the years, the E³ program has maintained a network of E³ teachers, inviting them to return to the TAMU campus for professional development opportunities (e.g., annual TAMU Teacher Summit, annual E³ Workshop) as well as to bring their students for campus visits. From a certification standpoint, the E³ program has served as professional development for the participants. The teachers received Continuing Professional Education credit for participating in the program. In addition, they received clock hours in the area of Differentiated Curriculum which contributes towards Texas Association of Gifted and Talented credit. Many of the teachers indicated that the E³ program provided some of the best professional development that they had ever received, and that the program had major effects on their teaching style. Some of their comments include:

- “Everything that I learned in the E³ summer research program has positively affected the way I teach and has helped me to be more selective of the activities I choose to incorporate in the curriculum.”
- “[The E³ program] 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 been much better equipped to show my students how the sciences are all very integrated. Understanding this helps the students understand how physics explains biological processes, or how chemistry can explain some basic physical concepts, etc. this connection helps students draw on prior knowledge, helping me more effectively teach my students.”
- “I have many more ideas to motivate students and show how math is applied in the real world such as engineering.”
- “I am always excited to share my experience at E³ program because it enlightened me to teach with a purpose.”
- “……this has been the best experience of my professional career.”
- “I really can’t think of a recommendation to make [for program improvement]. This program was amazing!”

Although NSF funding for this RET Site concluded in August 2013, the TAMU College of Engineering appreciates its value; E³ has been considered an integral component of the College’s outreach program. As such, the College plans to continue offering the E³ program in the future.

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