The Enrichment Experiences in Engineering (E3)

Dr. Robin L Autenrieth P.E., Texas A&M University

Dr. Robin Autenrieth was one of the principal investigators on the NSF-funded E3 RET grant. She is currently the Interim Department Head and a Professor in the Department of Civil Engineering at Texas A&M University and holds the A.P. and Florence Wiley III Professor. She earned a B.S. in biological sciences from the University of Maryland, and a M.S. and Ph.D. in environmental engineering from Clarkson University. She holds a professional engineering license in the state of Texas. Her early research focused on microbial systems for the degradation of target compounds. Her work has evolved to using a risk assessment framework to link contaminant concentrations with human exposures for predicting the potential for adverse health effects and identifying strategies to mitigate impacts. She has long promoted engineering awareness in the public education systems and hosts a STEM high school teacher program each summer.

Dr. Cheryl A Page, Texas A&M University

Cheryl Page is a Research Engineer in the Department of Civil Engineering at Texas A&M University. She has academic degrees in secondary education and civil engineering, with experience as a secondary mathematics teacher as well as an environmental engineering researcher. She can be reached by e-mail at capage@tamu.edu.

Dr. Karen L. Butler-Purry, Texas A&M University

Karen Butler-Purry is the Associate Provost for Graduate Studies and Professional Studies as well as a Professor in the Department of Electrical and Computer Engineering at Texas A&M University, College Station, Texas. She was one of the principal investigators on the NSF-funded E3 RET grant. Her research interests include computer and intelligent systems applications to power distribution systems and engineering education. She can be reached by e-mail at klbutler@tamu.edu.

Chance W. Lewis, University of North Carolina, Charlotte

Chance W. Lewis is the Carol Grotnes Belk Distinguished Professor and Endowed Chair of Urban Education at the University of North Carolina at Charlotte. He is also the Executive Director of The Urban Education Collaborative at UNC Charlotte. His research interests are in the areas of urban education and the achievement gap, recruitment and retention of teachers of color in urban settings, teacher education and African American student success in K-12 and higher education. He can be reached by e-mail at chance.lewis@uncc.edu.

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 (E^3) 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), E^3 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 E^3 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 [31].

- *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 E^3 program (2003-2013 E^3 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 E^3 teachers were from schools with high minority student populations (average 83% Hispanic and/or African American; average 69% economically-disadvantaged).

Previous E^3 program evaluation

Summative evaluation of the early years of the E^3 program focused primarily on qualitative questions to measure program objectives and anticipated outcomes[31]; a focus group session and responses to an online survey provided additional insights[32]. *Formative evaluation* of the E^3

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 E^3 workshop is hosted during the academic year to support the E^3 teacher network and maintain ties with the COE; (2) two E^3 master teachers (former E^3 participants) come to campus to work with the participants as they develop their E^3 classroom project; (3) teachers are required to create an E^3 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 E^3 cohort are encouraged to promote bonding within the cohort.

Methods

When (co-author) Dr. C. Lewis joined the E^3 team as an external evaluator in 2007, he developed an anonymous on-line post-program survey to be administered to all future E^3 cohorts. It included both summative- and formative-type statements/questions; providing a Likert-type scale[33] 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 E^3 cohorts, *pre-post* surveys were administered. After compiling and plotting the data from these survey responses, the E^3 team noticed inconsistences 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 E^3 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 E^3 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.[34] outline several quasi-experiment designs to consider when a control group is lacking (which was the case for the E^3 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 change[35]. 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[35]. Another possible concern with the *pre-post* survey design is *response shift bias*[34-35].

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[36], particularly in educational program surveys because these types of programs are designed to improve the participants' knowledge, skills, attitudes, to name a few.[37-38]. 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 E^3 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[36]. 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/attitudes/etc. 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[39]. 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 E^3 external evaluator restructured the questions using the *retrospective post-then-pre* format, and the surveys administered to the 2011, 2012, and 2013 E^3 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 E^3cohorts (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.

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

$$Percent\ Change\ (\%) = \left(\frac{Postprogram\ composite\ number}{Preprogram\ composite\ number} - 1.0\right) * 100$$

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.

<u>Provide engineering research experiences</u>

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 E^3 RET Program

Year	Aero.	Bio. & Ag.	Biomed.	Chem.	Civil	Computer sci/eng	Elec.	Indus.	Mech.	Nuclear
2004	1	1			3		1	1	1	
2005	2	1			1		1	1	1	
2006	1				1		1	2	1	
2007	1			1					3	
2008	1			1	2		1		1	2
2009					1		1		2	
2010							2		3	3
2011			2	2	1	1			1	3
2012			1	1	1			1	1	2
2013			1	1				1	3	2

*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."*

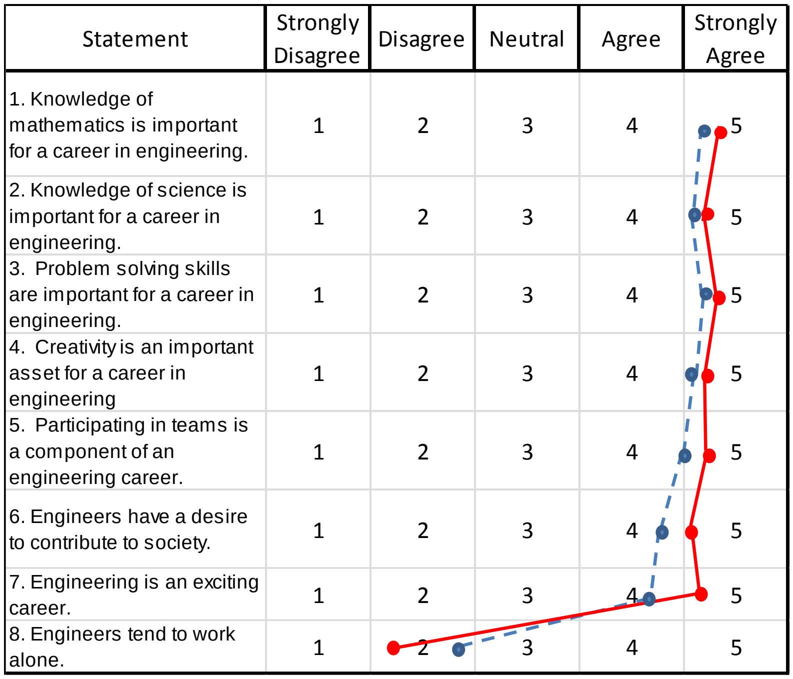
<u>Enhanced understanding of engineering</u>

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 E^3 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 E^3 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

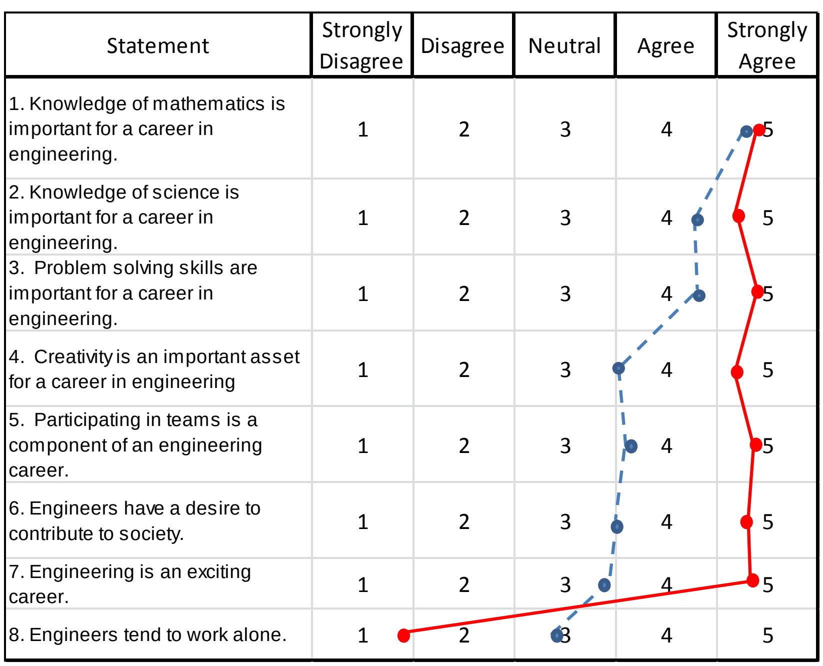
(Pre: - - - Post: ——)



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

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

(Pre: - - - Post: ——)



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

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

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

*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 E^3 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 E^3 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

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

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 E^3 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 E^3 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[40]. 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 E^3 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 E^3 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 E^3 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 E^3 program was particularly helpful. The teachers understand the scientific method process, but the engineering design process is unfamiliar to most of them. As the E^3 program matured, feedback from participating teachers inspired the E^3 team to incorporate more structured lectures on the engineering design process in subsequent E^3 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 E^3 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 E^3 lesson/activity in their classroom. For those teachers who were not able to conduct their E^3 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 E^3 cohort are in the process of implementing their E^3 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 E^3 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 E^3 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 ± 0.0.50 (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 E^3 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 E^3 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 E^3 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 E^3 experience (mean score 4. 54 ± 0.64). Regarding the dinner speakers, 59% *strongly agreed* and 34% *agreed* that the speaker presentations enhanced their E^3 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 E^3 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 E^3 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 E^3 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 E^3 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 E^3 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 E^3 program broadened the teachers' awareness of engineering careers.
6. The teachers felt that the E^3 program armed them with information and knowledge to promote the field of engineering to their students.

A "lesson learned" for the E^3 leadership team is in regards to survey design selection. In the case of the E^3 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, E^3 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 E^3 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 E^3 experience, conducting their E^3 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 E^3 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 E^3 program has maintained a network of E^3 teachers, inviting them to return to the TAMU campus for professional development opportunities (e.g., annual TAMU Teacher Summit, annual E^3 Workshop) as well as to bring their students for campus visits. From a certification standpoint, the E^3 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 E^3 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 E^3 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 E^3 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 E^3 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; E^3 has been considered an integral component of the College's outreach program. As such, the College plans to continue offering the E^3 program in the future.

Acknowledgments

The authors wish to thank the National Science Foundation for its support of the E^3 RET Site (EEC-*0227681, EEC-0601776 & EEC-090843).* Any opinions, findings, and conclusions/recommendations expressed in this material are those of the authors, and do not necessarily reflect the views of the National Science Foundation. Thanks are also extended to the Nuclear Power Institute, Chevron, and the Texas Workforce Commission (*Contract #1610WSW000*) for their financial support of the E^3 program.

References

1. National Academyof Sciences, National Academy of Engineering, and Institute of Medicine, *Rising above the gathering storm, revisited: Rapidly approaching category 5*. 2010, Washington, DC: National Academies Press.
2. US Department of Labor, *The STEM workforce challenge: The role of the public workforce system in a national solution for a competitive science, technology, engineering, and mathematics (STEM) workforce*. 2007, Washington, DC: author.
3. U.S. Department of Education *Students who study science, technology, engineering, and mathematics (STEM) in postsecondary education*. Stats in Brief, 2009. July, 1-25.
4. National Academy of Sciences, *Rising above the gathering storm: Energizing and employing America for a brighter economic future*. 2005, Washington, DC: National Academy Press.
5. National Science Foundation - National Center for Science and Engineering Statistics, *Science and Engineering Degrees: 1966-2008. Detailed Statistical Tables NSF 11-316,* 2011, National Science Foundation: Arlington, VA.
6. President's Council of Advisors on Science and Technology. *Engage to excel: Producing one million additional college graduates with degrees in science, technology, engineering, and mathematics*. 2012; Available from: http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast-engage-to-excel-final_feb.pdf.
7. Feder, M. *One Decade, One Million more STEM Graduates*. 2012; Available from: http://www.whitehouse.gov/blog/2012/12/18/one-decade-one-million-more-stem-graduates.
8. Dohm, A. and L. Shniper, *Occupational employment projections to 2016,* M.L.r.O. Bureau of Labor Statistics, Editor 2007. p. 86-125.
9. National Science Board, *Science and engineering indicators 2012*. 2012, Arlington VA: National Science Foundation, NSB 12-01.
10. Committee on Underrepresented Groups and the Expansion of the Science and Engineering Workforce Pipeline, *Expanding underrepresented minority participation: America's science and technology talent at the crossroads*. 2010, Washington, DC: National Academies Press.
11. National Academies and National Research Council Board On Science Education, *Evidence on Promising Practices in Undergraduate Science, Technology, Engineering, and Mathematics (STEM) Education*, 2008.
12. National Research Council, *Promising Practices in Undergraduate Science, Technology, Engineering and Mathmatics Education: Summary of Two Workshops*, 2011: Washington, DC. p. 97.
13. Demel, J.T., Gustafson, R.J., Fentiman, A.W., Freuler, R.J., an d J.A Merrill, *Bringing about marked increases in freshman engineering retention*. in *2002 ASEE Annual Conference and Exposition: Vive L'ingenieur, June 16, 2002 - June 19, 2002*. 2002. Montreal, Que., Canada: American Society for Engineering Education.
14. American Society for Engineering Education, *Profiles of engineering and engineering technology colleges*. 2011, Washington, DC: American Society for Engineering Education.

15. Dedicated Engineers *Minorities in engineering & related fields: Diversity analysis of student earning bachelor's degrees*. 2006. 2006.
16. Dedicated Engineers. *Women in engineering & related fields: Diversity analysis of students earning bachelor's degrees*. 2006.
17. Ennis, S.R., M. Rios-Vargas, and N. Albert, *The Hispanic population: 2010*, in *2010 Census Briefs*, U.S. Census Bureau, Editor 2011: Washington, DC. p. 16.
18. U.S. Census Bureau. *2010 Census Data*. 2010 Available from: http://2010.census.gov/2010census/data/.
19. Wulf, William, The Importance of Diversity in Engineering, in *Diversity in Engineering: Managing the Workforce of the Future*, National Research Council, The National Academies Press, 2002, pp 8-15.
20. Dick, T.P. and S.F. Rallis, *Factors and influences on high school students' career choices.* Journal for Research in Mathematics Education, 1991. **22**(4): p. 281-292.
21. Trenor, J.M., Yu, S.L., Waight, C.L., Zerda, K.S., and T.L. Sha, *The relations of ethnicity to female engineering students educational experiences and college and career plans in an ethnically diverse learning environment.* Journal of Engineering Education, 2008. **97**(4): p. 449-465.
22. Lovencin, W., F. Najafi, and N. Safai. *A review of strategies employed on minority recruitment and retention in engineering education*. 2007. Honolulu, HI, United States: American Society for Engineering Education, Chantilly, VA 20153, United States.
23. McWhirter, E.H., Torres, D.M., Salgado, S., and M. Valdez, *Perceived barriers and postsecondary plans in Mexican American and White adolescents.* Journal of Career Assessment, 2007. **15**(1): p. 119-138.
24. Nora, A., *The role of habitus and cultural capital in choosing a college, transitioning from high school to higher education, and persisting in college among minority and nonminority students.* Journal of Hispanic Higher Education, 2004. **3**(2): p. 180-208.
25. Pope, M.L. and B. Fermin, *The perceptions of college students regarding the factors most influential in their decision to attend postsecondary education.* College & University, 2003. **78**(4): p. 19.
26. Lindsley, L.L. and V.A. Burrows, *Work in progress - Changes in secondary school teachers' attitudes following a course in engineering design*, in *Frontiers in Education Conference, FIE, 37th ASEE/IEEE Frontiers in Education Conference*2007, Institute of Electrical and Electronics Engineers Inc.: Piscataway, NJ p. 2-12.
27. Hoh, Y.K., *Introduction to prominent women in chemical engineering: An outreach activitiy.* Journal of Women and Minorities in Science and Engineering, 2007. **13**: p. 377-390.
28. Cunningham, C. and M. Knight. *Draw an Engineer Test: Development of a Tool to Investigate Students' Ideas about Engineers and Engineering*. in *Proceedings of the 2004 American Society for Engineering Education Annual Conference and Exposition*. 2004. Salt Lake City, Utah: ASEE.
29. Cunningham, C., C. Lachapelle, and A. Lindgren-Streicher. *Assessing Elementary School Students Conceptions of Engineering and Technology*. in *Proceedings of the 2005 American Society for Engineering Education Annual Conference and Exposition*. 2005. Portland, OR: ASEE.
30. Baker, D.S., Krause, S., Kurpuis-Robinson, C., Roberts, C., and S. Yasar. *A Valid and Reliable Survey Instrument for Measuring K-12 Teachers' Perceptions and Needs on Design, Engineering, and Technology*. in *American Society of Engineering Education Conference Proceedings*. 2006. 2006-1120.
31. Autenrieth, R., Butler-Purry, Karen, Page, C., and L.D. Hurtado, *Enrichment experiences in engineering (E^3) for teachers summer research program*. in *American Society of Engineering Education (ASEE) Conference*. 2009. Paper No: AC 2009-1108
32. Page, C.A., Lewis, C., Autenrieth, R., and K. Butler-Purry, *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.* Journal of STEM Education, 2013. **14**(3): p. 10-16
33. Likert, R., *A technique for the measurement of attitudes.* Archives of Psychology 1932. **140**: p. 1-55.
34. Shadish, W.R., T.D. Cook, and D.T. Campbell, *Experimental and quasi-experimental designs for generalized causal inference*. 2002, Boston: Houghton Mifflin Co. p. 103-115.
35. Gall, M.D., J.P. Gall, and W.R. Borg, *Educational research: An introduction* 6th ed. 2007, Boston: Pearson.
36. Howard, G.S. and P.R. Dailey, *Response-shift bias: A source of contamination of self-report measures.* Journal of Applied Psychology, 1979. **64**: p. 144-150.
37. Howard, G.S., *Response-shift bias a problem in evaluation interventions with pre/post self-reports.* Evaluation Review 1980. **4**(1): p. 93-106.

38. Pratt, C.C., W.M. McGuigan, and A.R. Katzev, *Measuring program outcomes: Unsing retrospective pretest methology.* American Journal of Evaulation, 2000. **21**(3): p. 341-349.
39. Howard, G.S., Milliham, J., Slaten, S., and L. O'Donnell, *Influence of subject response-style effects on retrospective measures.* Applied Psychological Measurement, 1981. **5**: p. 144-150.
40. National Research Council, *Gender differences at critical transitions in the careers of science, engineering and mathematics faculty*, National Academies, Editor 2009: Washington, DC. p. 373.