Enrichment Experiences in Engineering (E^3) Summer Teacher Program: Analysis of Student Surveys Regarding Engineering Awareness

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Abstract

Ongoing efforts across the U.S. to encourage K-12 students to consider engineering careers have been motivated by concerns that the workforce pipeline for this profession is shrinking. Enlightening K-12 teachers about engineering is one strategy to encourage student interest in the discipline. The Enrichment Experiences in Engineering (E^3) for Teachers Summer Research Program at Texas A&M University engages high school math and science teachers in an engineering research experience. Since 2003, the E^3 program has hosted over 190 teachers, most of whom teach in low socioeconomic status (SES) schools with a high percentage of minority students. The mission of the E^3 program is to educate and excite teachers about the field of engineering so that they can introduce engineering concepts to their students and encourage them to consider a career in engineering. During the summer program, teachers are involved in: (1) hands-on participation in current engineering research, (2) activities to broaden their awareness of engineering and career opportunities for their students, and (3) development of engineering-related lesson plans for implementation in their high school classroom. As part of their lesson plan implementation, teachers from the 2009-2013 cohorts were required to administer pre- and post-surveys to their students. The identical survey was administered to the students before and after classroom implementation of the E^3 lesson/activity. The survey included five questions regarding engineering awareness and three questions regarding college plans. The survey was designed to determine if the students exhibited an increased awareness of engineering after implementation of the E^3 lesson/activity and if there was any progress in forming college plans (specifically as it pertains to engineering.)

This paper presents the student survey findings. Forty-six (46) teachers from Cohorts 2009-2013 administered the pre- and post-survey to their students (2,263 total). For the "engineering awareness" questions, there were large differences in the pre- vs. post-survey responses that indicated increased awareness of engineering. Depending on the question, the percentages ranged from 20% to 113%. Regarding increased interest in considering an engineering major in college, in the pre-survey, 32.4% of the students indicated interest in pursuing an engineering major ("agree" or "strongly agree" responses). In the post-survey, that percentage rose to 40.6%. These findings demonstrate the value in using teachers to expose high school students to engineering to create awareness for students who might not have considered this career path.

Keywords: engineering, high school, teacher research experiences, student awareness & interest in engineering, student survey

Background

Introduction

For several years there have been concerns as to whether the U.S. will have the strong technical workforce necessary to maintain economic competitiveness (US Department of Labor 2007, U.S. Department of Education 2009, National Academy of Sciences, National Academy of Engineering et al. 2010, National Science Foundation - National Center for Science and Engineering Statistics 2011, Feder 2012, President's Council of Advisors on Science and Technology 2012). Based on the projected workforce outlook, the future U.S. workforce needs will require more engineers; the Bureau of Labor Statistics predicts seven percent (7%) job growth for the engineering field over the next decade (Bureau of Labor Statistics 2017).

From a long-term historical perspective, the number of B.S. engineering degrees awarded peaked in the mid-1980s and began declining to a low in 2001 (National Science Foundation - National Center for Science and Engineering Statistics 2015). However, in recent years there has been a steady increase in the numbers of students enrolled in engineering programs and an increase in the number of bachelor's degrees awarded (National Science Board 2014, National Science Foundation - National Center for Science and Engineering Statistics 2015, Yoder 2015).

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 engineering solutions to societal needs (Wulf 2002, Wulf and Fisher 2002). Although there have been concerted efforts to broaden participation of students underrepresented in engineering (i.e., females as well as Hispanics, African Americans, and Native Americans) (Committee on Underrepresented Groups and the Expansion of the Science and Engineering Workforce Pipeline 2010, Neilsen, Planning Committee on Evidence on Selected Innovations in Undergraduate STEM Education et al. 2011), nationwide engineering enrollment numbers and degrees awarded to these groups continue to remain well below parity (Ohland, Brawner et al. 2011, American Society for Engineering Education 2012, National Science Board 2014, Yoder 2015). With the changing demographics of Texas (Ennis, Rios-Vargas et al. 2011) and the country (U.S. Census Bureau 2010), it is essential to recruit from underrepresented minority groups, as well as women, to help satisfy projected engineering workforce demands.

To increase K-12 students' interest in engineering, various approaches have been utilized, including summer camps (Northern 2007, Paterson and Jarvie 2008, Yilmaz, Ren et al. 2010), after-school programs (Ferreira 2001, Miller 2003, Blanchard, Judy et al. 2015), and competitions (Nugent, Barker et al. 2009). Enlightening K-12 teachers about engineering is another effective approach to encourage student interest in the discipline. Teachers are influential in career choices for high school students, particularly STEM careers (Dick and Rallis 1991, Pope and Fermin 2003, Nora 2004), and are especially helpful for females and underrepresented minority students (Lovencin, Najafi et al. 2007, Trenor, Yu et al. 2008, Van Haneghan, Pruet et al. 2015).

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. The National Science Foundation (NSF) recognized the influence of teachers on student career choices when establishing the Research Experiences for Teachers (RET) in Engineering and Computer Science Program (National Science Foundation) and approximately 100 currently funded NSF RET programs exist nationwide that provide opportunities for teachers to increase their understanding of engineering. One RET program, Enrichment Experiences in Engineering (E^3), has been offered as a summer program at Texas A&M University (TAMU) since 2003. During the program, high school math and science teachers participate in engineering research, learn about engineering and engineering careers, and develop engineering-related activities to be implemented in their classroom the following academic year. For several of the E^3 cohorts, student pre- and post-surveys were a required component of the lesson plan implementation. The research presented in this paper focuses on survey responses from the participants' students regarding their awareness of engineering and interest in pursuing a college degree in engineering.

Engineering in the K-12 Classroom

Historically speaking, most K-12 students and teachers have marginal awareness of the engineering profession (Cunningham and Knight 2004, Cunningham, Lachapelle et al. 2005, Baker, Krause et al. 2006), and their perceptions are often misleading. Many K-12 students associate engineering with physical labor, such as "fixing things", and as boring; they may perceive engineers as Caucasian males and somewhat "nerdy" (Gibbons, Hirsch et al. 2004, Cunningham, Lachapelle et al. 2005, Oware, Capobianco et al. 2007, Johnson, Ozogul et al. 2013, Montfort, Brown et al. 2013). Many teachers also have stereotypical misconceptions about engineering (Hoh 2007, Lindsley and Burrows 2007, Nathan 2011) such as assuming that engineers need to be "math wizards." Yasar et al. (Yasar, Baker et al. 2006) noted that when teachers have a narrow (and often inaccurate) view of engineering, they may not encourage all able students to consider the field as a career; they may misrepresent the skill requirements of engineering careers to students. Other studies had similar findings . Unfortunately, there has been little exposure to engineering concepts in the formal K-12 curricula, which contributes to the general lack of understanding of engineering and what engineers do. However, this has been changing nationwide, albeit slowly.

Over two decades ago, the National Research Council (NRC) released the National Science Education Standards (NSES) which called for authentic inquiry activities in the K-12 science classroom while also emphasizing the importance of coordinating mathematics and science programs (National Research Council 1996). When Fadali and Robinson reviewed the standards, they noted that engineering and technology were not identified as logical means to facilitate the coordination of the two programs, though introducing engineering concepts in the classroom would also align with the call for more authentic inquiry activities (Fadali and Robinson 2000). In 2009, the NRC published a report outlining various strategies to incorporate engineering into the K-12 classroom (National Research Council 2009), and in this report they distilled their suggestions into three primary options: (a) *ad hoc* infusion, (b) stand-alone courses, and (c) interconnected STEM education. In 2012, the NRC released "A Framework for K-12 Science Education" (National Research Council 2012) which served as the foundation for the Next Generation Science Standards (NGSS) (National Research Council, National Science Teachers Association et al. 2011). The 2013 release of these engineering-infused national science standards (i.e., the NGSS) addresses incorporation of engineering into the K-12 curriculum . As outlined in the NGSS, science and engineering are integrated into science education where engineering design and scientific inquiry are given equal emphasis. Adoption of the NGSS is on a state-by-state basis and more than two dozen states have adopted the standards.

Texas, which has not adopted the NGSS, has several state-approved engineering-related courses for the high school classroom (Texas Education Agency 2010). However, it is subject to the discretion of the individual school districts as to whether they offer any of the courses, and there are a variety of obstacles when trying to incorporate engineering into the high school classroom, including inadequate textbooks and insufficient teacher preparation. Other formal mechanisms to get engineering into the Texas high-school setting include Project Lead The Way (Project Lead The Way) and STEM academies such as T-STEM (Texas Education Agency).

But there are other ways to bring engineering into the classroom besides formal coursework. The E^3 program models the *ad hoc* infusion strategy outlined in the National Research Council 2009 report (National Research Council 2009) by requiring participating E^3 teachers to develop an engineering-related inquiry-based activity for implementation in their high school classroom. The *ad hoc* infusion of engineering ideas and activities into existing mathematics, science or technology curricula requires minimal changes in curriculum structure and as such is the most direct and least complicated strategy to incorporate engineering into the K-12 classroom setting.

The Enrichment Experiences in Engineering (E^3) Program

Since inception, E^3 has been an integral component of the TAMU College of Engineering's comprehensive outreach plan which has the overarching goal to increase the pool of undergraduate engineering applications into the COE. The College had already established relationships with approximately 12 partner high schools in (diverse) Houston Independent School District as well as in (primarily Hispanic) South Texas. Initially, teachers were recruited from these partner high schools to further strengthen the partnerships and encourage their qualified students to apply to the TAMU engineering program. As the E^3 program matured, recruiting efforts expanded beyond the original partner schools to other high schools with diverse student populations.

During the timeframe of NSF funding (i.e., 2003-2013), the E^3 program was a four-week summer residential program at Texas A&M University where high school science and mathematics teachers were matched with engineering faculty and participated in a research experience. During the summer program, teachers were involved in: (a) hands-on participation with current engineering research, (b) development of an engineering project for implementation in their high school classroom, and (c) activities to broaden their awareness of engineering career opportunities for their students. A brief summary of the E^3 summer activities is provided below. More details on the E^3 program can be found elsewhere (Autenrieth, Butler-Purry et al. 2009, Page, Lewis et al. 2013).

Working in pairs, E^3 teachers participated in research activities in their faculty mentor's laboratory where they learned about the current status of emerging technologies and research and received informal instruction in research methodology and science theory appropriate to their research experience. Each teacher created a 3' x 4' poster on their research topic that they could display in their classroom. The teachers later reported that the posters served as excellent informal conversation starters with students in regards to engineering and college/career planning, in general.

During their summer experience, the teachers received instruction on the engineering design process and developed hands-on classroom activities that incorporated the design process. Each teacher's unique classroom unit integrated an aspect of their research while maintaining state curricular standards. The length of the E^3 classroom unit varied between teachers, typically between 4-8 instructional days, depending on their course scope and sequence constraints.

Field trips to high-tech industry plants allowed teachers to see firsthand what engineers do in industry. Other opportunities to broaden the teachers' awareness of engineering included weekly dinners during which an engineering faculty member discussed his/her research area (e.g., alternative energy sources, tissue engineering, and cybersecurity) as well as lab tours of the participating faculty mentors. These activities provided many engineering-related examples to share with their students.

During the 2003-2013 time period of NSF funding, 150 teachers (48% White, 27% Hispanic, 15% African American, 9% Other) participated in the program; most E^3 teachers were from schools with a high percentage of underrepresented minority student populations (average 83% Hispanic and/or African American; average 69% economically-disadvantaged).

Programmatic evaluation efforts associated with the early years of the E^3 program (ie., 2003-2007) focused primarily on qualitative questions to measure program objectives and anticipated outcomes. In exit interviews, the participants indicated that they had a better understanding of engineering and engineering careers, gained deeper understanding of their teaching subject and appreciated the opportunity to provide information on college planning and admissions process into the TAMU engineering program (Autenrieth, Butler-Purry et al. 2009). When assessing *longer-term programmatic impact* on the early E^3 cohorts, the teachers were invited to respond to an anonymous online survey and/or participate in face-to-face focus group session(s). These opportunities occurred well after their summer experience. The respondents indicated that the E^3 experience had a positive effect on their teaching and professional development and that they have been better able to promote engineering to their students (Page, Lewis et al. 2013).

When co-author Dr. Chance W. Lewis joined the E^3 team as an external evaluator in 2007, the program evaluation plan was augmented to include (a) more comprehensive surveying of the participants (Autenrieth, Page et al. 2014, Autenrieth, Lewis et al. 2017) and (b) student surveys to determine if the teachers' E^3-developed classroom activities were successful in transferring information about engineering to their students. For the latter E^3 cohorts (2008-2013), online anonymous pre-post surveys were administered to the participants at the beginning/conclusion of their E^3 summer experience. Survey findings indicated that the participants experienced substantial changes in the following: (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 (Autenrieth, Page et al. 2014). An effort to assess a long-term program impact on all previous E^3 participants involved a mixed-method study that included an online survey as well as focus group interviews. The responding teachers indicated that in the long-term (i.e., over the years), they have continued to promote engineering to their students. Due to their E^3 experience, they have been better able to assist their students with college and career advice, better able to explain the importance of STEM, and better able to promote engineering as a potential career to their students (Autenrieth, Lewis et al. 2017).

These previous publications on the E^3 program evaluation (Autenrieth, Butler-Purry et al. 2009, Page, Lewis et al. 2013, Autenrieth, Page et al. 2014, Autenrieth, Lewis et al. 2017) focused on the E^3 participants and their perceptions of E^3 programmatic impact on themselves and on their students. In this paper, the results of the student surveys are investigated as a measure to assess the E^3 program's impact (via the teachers) on student awareness of engineering and interest in engineering as a potential career.

Methods

Overview

In the early years of the program, the E^3 leadership team recognized that any attempt to assess (indirect) impact on students would be based on teacher perceptions. For a more targeted approach to assess student impact, the idea of a student survey was proposed. The survey could help teachers informally measure students' increased awareness of the engineering field and engineering careers as well as interest in a college major in engineering. Moreover, survey findings could inform teachers for future engineering-related classroom activities as well as provide information to the E^3 team in terms of possible program modifications. The survey was created using internal (i.e., in-house) expertise: (a) the E^3 external evaluator, (b) the E^3 team as well as (c) E^3 master teachers (i.e. former E^3 participants who had been recruited to return and mentor a current cohort of participants). Survey details are provided in the following section.

Participants from the 2009-2013 E^3 cohorts were required to survey their students regarding their awareness of engineering and engineering disciplines/careers. A total of 46 participating teachers from these five cohorts administered pre- and post-surveys to their students. Teacher demographics are provided in Table 1. In Table 2, their high schools are categorized according to the size of the community in which they are located. The student population demographics for these 46 teachers' schools were on average: 64% Hispanic and/or African American, 59% economically-disadvantaged. The courses taught by these teachers and how many students were enrolled in each course are summarized in Table 3.

Female	22
Male	24
Caucasian	24
Hispanic	11
African American	7
Asian	4
Other	-

Table 1. Teacher Demographics

Survey Questions Assessing Students' Engineering Awareness and College Plans

The E^3 team was interested in determining if the teachers were able to increase their students' awareness of the engineering field as well as how engineers impact their lives (and society in general). The team was also interested in the students' college plans. To assess awareness and interest, a total of eight questions were

Location of School	#Students	# E^3 teachers
Rural town <20,000 pop.)	357	11
Small/Mid-size City (36,000-325,000 pop.)	583	9
Urban (>1,000,000 pop.)	1,323	26
TOTAL	**2,263**	**46**

Table 2. High School Setting

Courses Taught	# Students Taking the Course	# E^3 Participants Teaching the Course
Algebra I	158	5
Geometry & Pre-AP Geometry	292	5
Algebra II & Pre-AP Algebra II	216	5
Calculus	33	2
Biology/Honors Biology	153	2
Chemistry & Pre-AP Chemistry	554	8
Physics & Pre-AP Physics	627	12
AP Biology	53	2
Other (e.g., aquatic science, anatomy & physiology)	132	4
Engineering-related courses	28	2
TOTAL	**2,263**	**46**

Table 3. High School Courses Taught

developed and the teachers were asked to administer the questions via a *pre-post survey* format to their students. Specifically, the students took the pre-survey prior to the teacher's E^3-developed classroom unit and then answered the same set of questions at some point in time following the E^3 unit (i.e., post-survey). Teachers were encouraged to administer the pre-survey well in advance of the E^3classroom activity(ies) and to wait an (undefined) period of time after completion of the activity(ies) to administer the post-survey.

The engineering-related questions were:

1. *What engineered devices do you have today that your parents did not have when they were children?*
2. *Name some world problems that engineers could solve.*
3. *How do engineers make our lives more comfortable?*
4. *Name as many engineering fields as you can.*
5. *Which sentence describes an engineer? (multiple choice)*

For Questions 1-4, the students were asked to list as many examples as they could think of (maximum of 10). Question 5 was a multiple-choice question and the students had three responses to select from.

Questions 6-8 on the survey addressed the students' college plans. These questions had a Likert-type scale of responses for students to select from (ie., *strongly disagree, disagree, agree, strongly agree*). The questions were:

6. *I am planning to go to college.*
7. *I am enrolled in or planning to take advanced level classes that will prepare me for college.*
8. *I am considering engineering as a major in college.*

Each teacher was required to compile and summarize the results of their students' pre- and post-surveys, then submit their survey summaries to the E^3 team. The copy of the survey is provided in the appendix.

Data Analysis Calculations

All student responses were compiled and analyzed as outlined below.

For Questions 1-4: For each question, the number of examples cited by all students was compiled. To compare the pre- and post-responses, a percent change in the number of examples cited was calculated for each question using the following equation:

$$\textbf{Percent Change (\%)} = \left(\frac{\textbf{Number of examples cited in post} - \textbf{survey}}{\textbf{Number of examples cited in pre} - \textbf{survey}} - 1.0\right) * 100$$

For Question 5: The total number of students who correctly answered the question was calculated for both the pre-survey and the post-survey. To determine the percent change of students who correctly answered the question in the post-survey (as compared to the pre-survey), the following equation was used:

$$\textbf{Percent Change (\%)} = \left(\frac{\textbf{Number of students with correct response on post} - \textbf{survey}}{\textbf{Number of students with correct response on pre} - \textbf{survey}} - 1.0\right) * 100$$

For Questions 6-8 (related to college plans): Each response type was assigned a numeric value: *strongly agree (4 points), agree (3 points), disagree (2 points), strongly disagree (1 point)*. Using these numeric values, each student response received an assigned value, the numbers were compiled and the average calculated for both sets of responses (ie., pre- and post) for each question. The percent change was calculated for each question using the following equation:

$$\textbf{Percent Change (\%)} = \left(\frac{\textbf{Post} - \textbf{survey compiled number}}{\textbf{Pre} - \textbf{survey compiled number}} - 1.0\right) * 100$$

where the compiled number was determined by multiplying the student responses by the respective numeric values and summing the calculated values.

Results

Pre-Post Responses to Questions Addressing Engineering Awareness and College Plans

For the 46 teachers in the 2009-2013 cohorts who provided the summary of their students' pre-and post-survey results, the total number of student respondents was 2,263. However, due to occasional teacher error in reporting and/or some students not answering all questions, the total number of responses for a given question may vary slightly (< 1%).

For Question 1, students were asked to name some engineered devices that did not exist when the students' parents were children (Figures 1a and 1b). The results for 2009 E^3 Cohort's students are presented separately since the summary reporting sheet was slightly modified for subsequent E^3 cohorts; specifically, the 2009 teachers were asked to group the number of cited examples in a different format. In Figure 1a, 2009 E^3 Cohort's students (n = 417) provided 22% more examples in the post-survey as compared to the pre-survey. In Figure 1b, the 2010-2013 E^3 Cohorts' students (n = 1,843) provided 36% more examples in the post-survey as compared to the pre-survey. If the responses were broken out by cohort, then the percentages of additional examples provided in the post-survey for Cohorts 2010 through 2013 are 26%, 43%, 35%, and 34%, respectively.

For Question 2, students were asked to list some world problems that engineers could solve (Figure 2). The students associated with the 2009-2013 E^3 Cohorts (n = 2,243) provided 78% more examples in the post-survey as compared to the pre-survey. If the responses were broken out by cohort, then the percentages of additional examples provided in the post-survey as compared to the pre-survey for Cohorts 2009 through 2013 are 65%, 31%, 113%, 93% and 59%, respectively.

For Question 3, students were asked to list examples of how engineers make our lives more comfortable (Figure 3). The students associated with the 2009-2013 E^3 Cohorts (n = 2,268) provided 42% more examples in the post-survey as compared to the pre-survey. If the responses from each cohort's students are analyzed separately, then the percentages of additional examples provided in the post-survey as compared to the pre-survey for Cohorts 2009 through 2013 are 20%, 41%, 53%, 54%, and 37%, respectively.

For Question 4, students were asked to name as many engineering fields as they can (Figure 4). The students associated with the 2010-2013 E^3 cohorts students (n = 1,836) provided 49% more examples in the post-survey as compared to the pre-survey. If the responses from each cohort's students are analyzed separately, then the percentages of additional examples provided in the post-survey as compared to the pre-survey for Cohorts 2010 through 2013 are 35%, 43%, 69%, and 27% respectively.

For Question 5, students were asked to identify the statement that accurately describes an engineer (Figure 5). The multiple choice options are listed below; the correct response is "C."

A. *A person who uses the scientific method to make conclusions based on experimentation*

B. *A person who uses math to research phenomena in the natural world*

C. *A person who integrates science and math to fulfill a need in society*

Collectively (i.e. all students associated with 2009-2013 cohorts; n=2,230), 19% more students correctly answered the question in the post-survey as compared to the pre-survey. If the responses from each cohort's students are analyzed separately, then the percentage

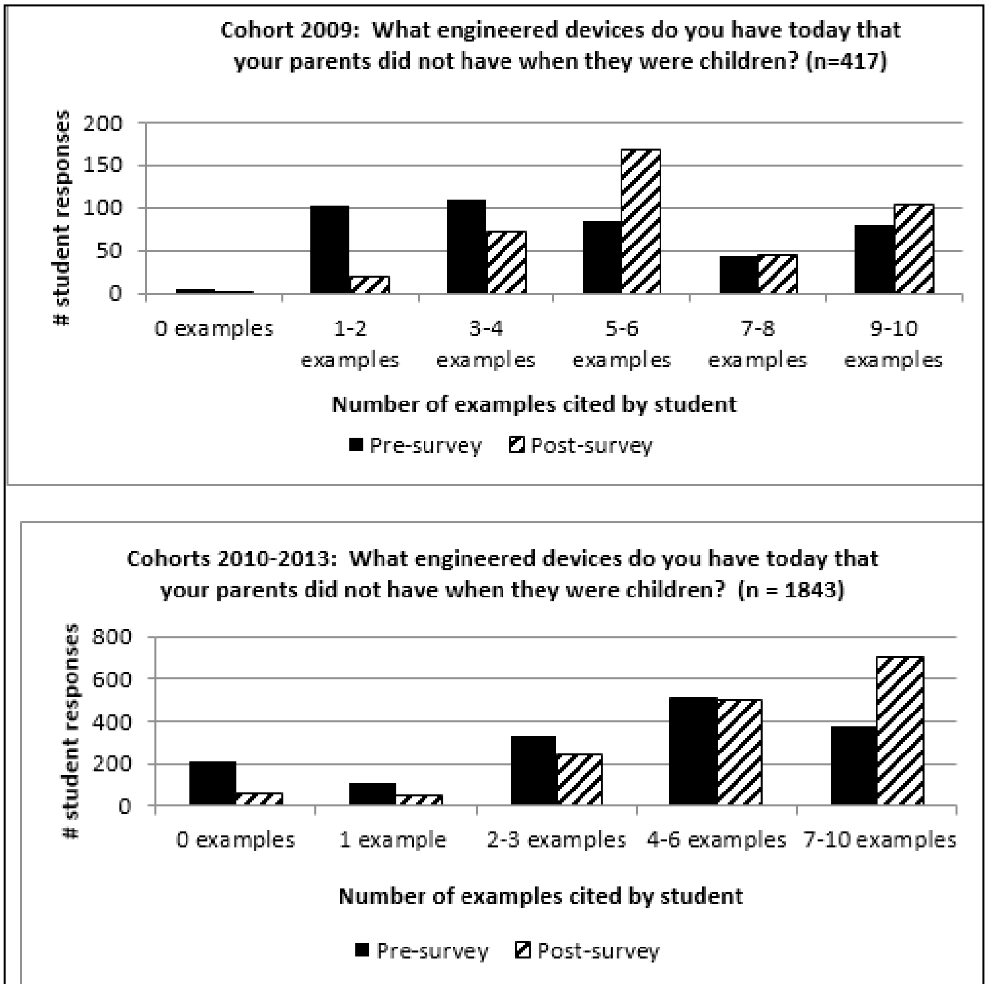


Figure 1 (a & b): Student Pre- and Post-Responses to Question 1

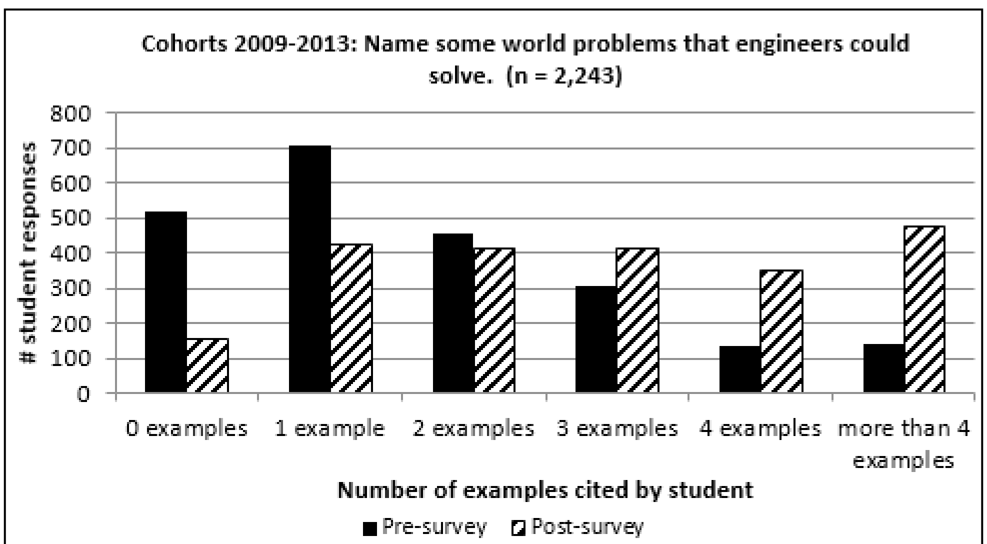


Figure 2: Student Pre- and Post-Responses to Question 2

increase of correct answers provided in the post-survey as compared to the pre-survey for Cohorts 2009 through 2013 are 18%, 4%, 28%, 12%, and 19%, respectively.

For Question 6, students were asked whether they planned to go to college. Based on a 5-*point* Likert scale, 2009 Cohorts' student responses are presented in Figure 6a (n=420); the average scores (pre and post) are 4.66 and 4.66, respectively. For subsequent cohorts (2010-2013), the students selected their responses from a 4-*point* Likert scale (Figure 6b, n=1,828). The combined average scores were 3.48 (pre-survey) and 3.56 (post-survey). This represents a 3% shift towards the "agreement" end of the Likert scale.

For Question 7, students were asked about their academic preparation for college (i.e., college-prep high school courses they were taking or planning to take). Based on a 4-point Likert scale, the 2010-13 cohorts' student responses are presented in Figure 7 (n=1,799). The combined average scores were 3.11 (pre-survey) and 3.14 (post-survey). This represents a 2% shift towards the "agreement" end of the Likert scale.

For Question 8, students were asked whether they were considering a major in engineering. Based on a 5-point Likert scale, 2009 Cohort student responses are presented in Figure 8a (n=420); the average scores (pre and post) are 2.77 and 2.92, respectively. Comparing the averages (pre versus post), there was an 8.2% shift towards the "agreement" end of the Likert scale. For subsequent cohorts, the students selected their responses from a 4-point Likert scale (Figure 8b, n=1,790) and the pre and post average scores were 2.18 and 2.34, respectively. This represents a 7.4% shift towards the "agreement" end of the Likert scale.

However, when looking at the tallied responses and calculating percent change for each of the response types, some changes (pre vs. post) are more pronounced. For example, the number of "strongly disagree" responses dropped 25.5% and 19.2% for Figures 8a and 8b respectively. The number of "disagree" responses dropped 12.3% and 7.9% for Figures 8a and 8b respectively. The number of "agree" responses increased 26.4% and 23.4% for Figures 8a and 8b, respectively; and the number of "strongly agree" responses increased 30.4% for Figure 8b.

Discussion

Regarding Engineering Awareness Questions

For the first four "engineering awareness" questions (Figures 1-4), there were significant differences in the pre- vs. post-survey responses. The percentages indicating increased awareness ranged from 20% (Figure 3, Cohort 2009) to 113% (Figure 2, Cohort 2011).

To further explore the findings, individual teacher data were further investigated to determine those circumstances that could yield larger increases in engineering awareness. Four (4) questions were considered to determine if there were additional trends:

1. Did students in smaller communities demonstrate increased engineering awareness as compared to students in mid-size cities or urban areas?
2. Did students in higher-level courses (e.g., Algebra II, Chemistry, Physics) demonstrate increased awareness as compared to students in lower-level courses (e.g., Algebra I, Geometry, Biology)?
3. Did the number of classroom implementation days for the E^3-related activity make a difference in student awareness of engineering?

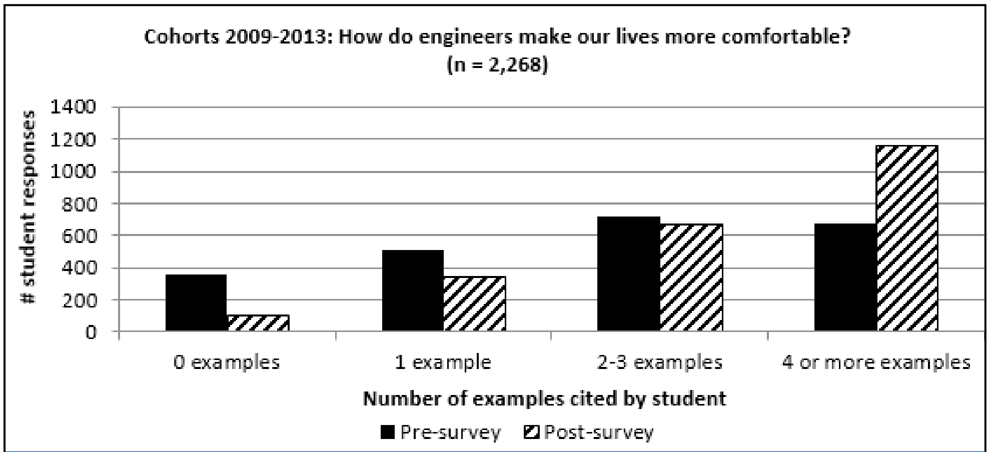
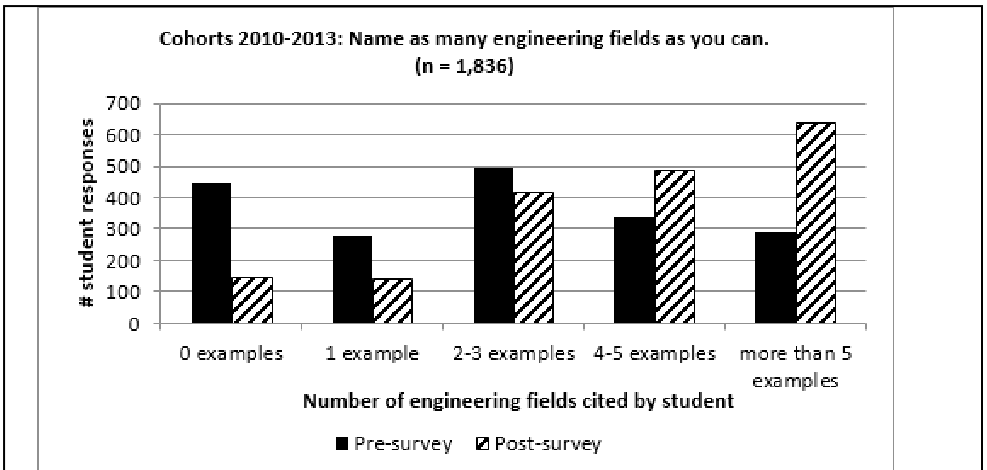


Figure 3: Student Pre- and Post-Responses to Question 3



Note: This question was not included on the pre-post surveys administered to Cohort 2009's students.

Figure 4: Student Pre- and Post-Responses to Question 4

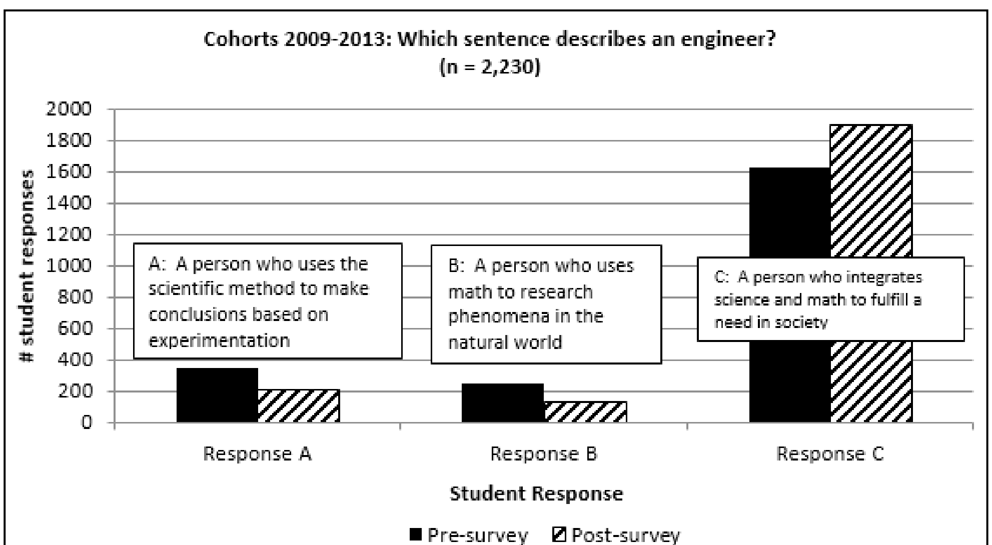


Figure 5: Student Pre- and Post-Responses to Question 5

4. Did the years of teaching experience make a difference in increased student performance regarding engineering awareness?

These questions did not reveal additional trends in student awareness of engineered devices before or after the classroom activity(ies) (Figure 1). There were seven (7) teachers whose classes provided at least 90% more examples in the post-survey as compared to the pre-survey. Three (3) of these teachers were from rural areas, two (2) were from mid-sized cities and two (2) were from urban cities. Four (4) of the teachers taught lower-level courses (Algebra I, Geometry) and three (3) of the teachers taught higher-level courses (Algebra II, Physics, Anatomy & Physiology). The number of days for their E^3 units varied from 4 days to 7 days. The range in teaching experience was 4-10 years.

When asked world problems that engineers could solve (Figure 2), the findings did not reveal any additional trends. There were nine (9) teachers whose classes provided at least 90% more examples in the post-survey as compared to the pre-survey. One (1) of these teachers was from a rural area, three (3) were from mid-sized cities and five (5) were from urban cities. Three (3) of the teachers taught lower-level courses (Algebra I, Biology, Geometry) and six (6) of the teachers taught higher-level courses (Algebra II, Chemistry, Physics). The number of days for their E^3 units varied from 4 days to 8 days. The range in teaching experience was 4-18 years.

No additional trends were found regarding examples of how engineers make life more comfortable (Figure 3). There were eleven (11) teachers whose classes provided at least 90% more examples in the post-survey as compared to the pre-survey. Four (4) of the teachers were from a rural area, two (2) were from mid-sized cities and five (5) were from urban cities. Six (6) of the teachers taught lower-level courses (Algebra I, Biology, Geometry) and five (5) of the teachers taught higher-level courses (Algebra II, Chemistry, Physics). The number of days for their E^3 units varied from 4 days to 8 days. The range in teaching experience was 2-23 years.

For Figure 4 (i.e., naming engineering fields), the findings again demonstrated no additional trends. There were eleven (11) teachers whose classes provided at least 90% more examples in the post-survey as compared to the pre-survey. Four (4) of the teachers were from a rural area, four (4) were from mid-sized cities and three (3) were from urban cities. Seven (7) of the teachers taught lower-level courses (Algebra I, Biology, Geometry) and four (4) of the teachers taught higher-level courses (Algebra II, Chemistry, Physics, AP Biology). The number of days for their E3 units varied from 4 days to 13 days. The range in teaching experience was 2-10 years.

When asked which phrase describes an engineer (Figure 5), the percentage of students that answered the question correctly in the pre-survey was seventy-three percent (73%). The percentage rose to 85% in the post-survey. Since the students, in general, performed well on this question (pre and post), the individual teacher data were not further investigated.

This analysis suggests that none of the four factors investigated (i.e. the city/town population size where the high school is located; the level of subject matter; the number of classroom implementation days for the E^3 unit; the years of teaching experience) appear to affect overall student performance in regards to increased awareness of engineering.

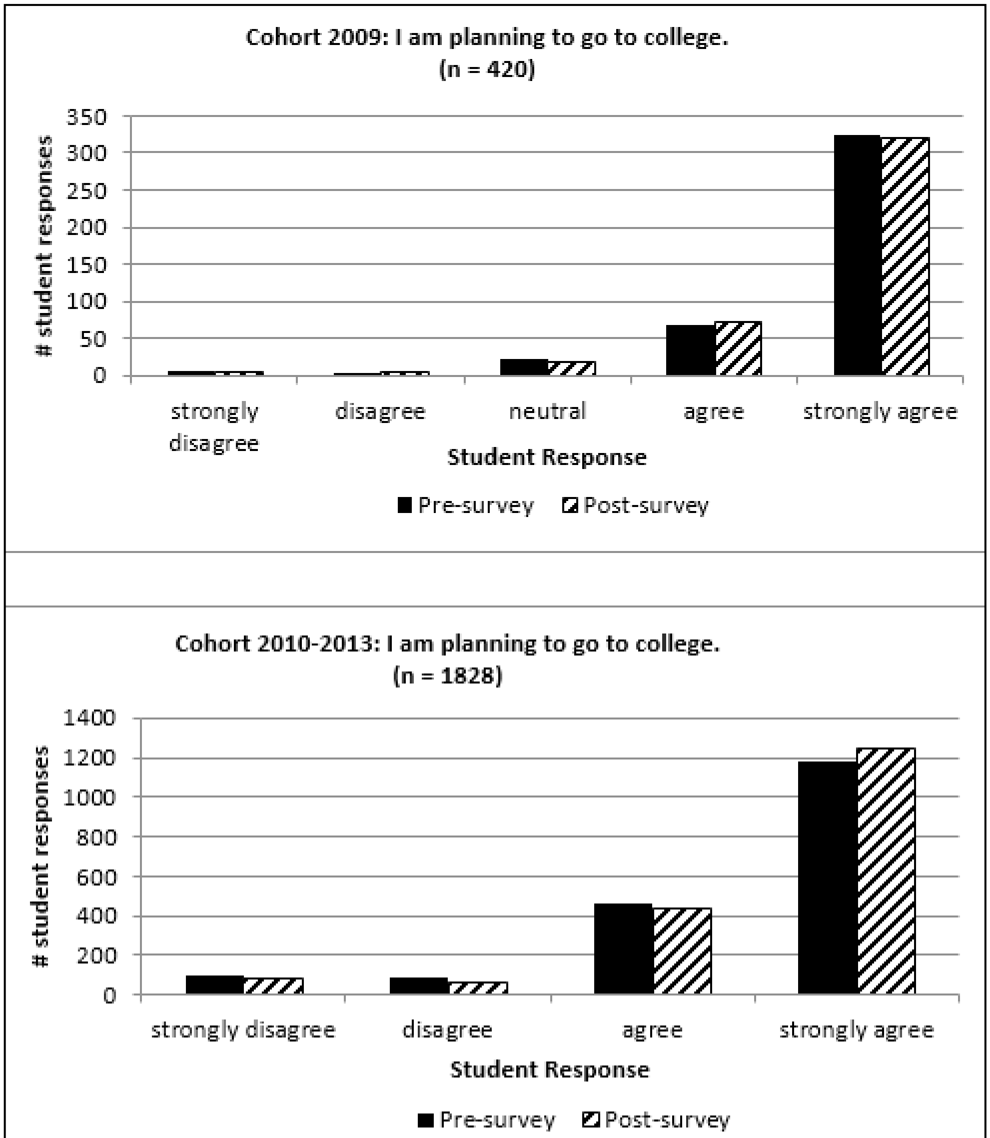
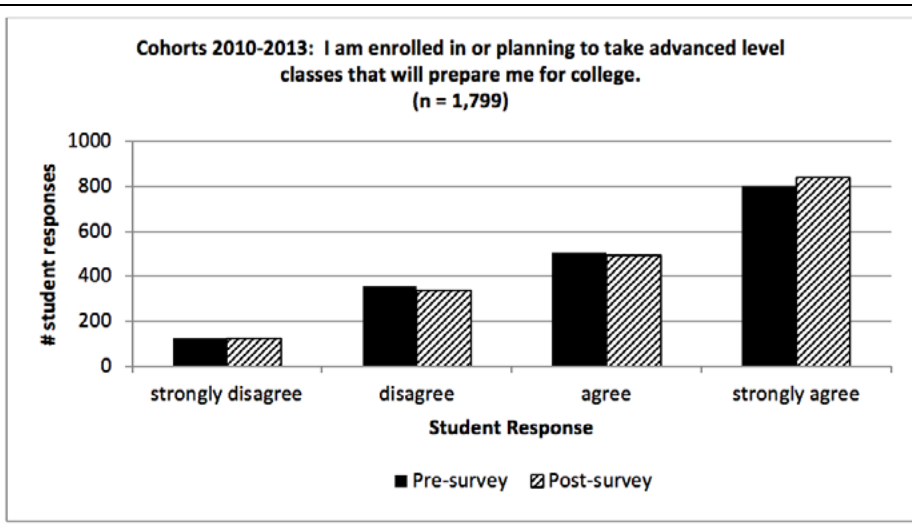


Figure 6 (a & b): Student Pre- and Post-Responses to Question 6



Note: This question was not included on the pre- and post-surveys administered to Cohort 2009's students.

Figure 7: Student Pre- and Post-Responses to Question 7

Another possible factor not addressed in this discussion is "*teacher effectiveness*." How much effect does the individual teacher have on his/her students and their academic performance? Various research studies have investigated the issue of *teacher effectiveness*. One approach to teacher-performance research is the "value-added" assessment which focuses on student academic achievement gains over a given year that can be attributed to a district, a school, or an individual teacher. The gains in academic achievement are the "value" that the teachers, schools and districts add. A comprehensive review of value-added research by the RAND Corporation found convincing evidence of the differential effect that individual teachers had on their students' academic progress (McCaffrey, Lockwood et al. 2003). Other studies had similar findings (Rivkin, Hanuskeh et al. 2000, Rowan, Correnti et al. 2002, Nye, Konstantopoulos et al. 2004).

When comparing student performance as it relates to increased student awareness to engineering, teacher effectiveness could explain the changes. Other factors could be involved, but this survey was not part of a study designed to identify any specific factors affecting student performance.

Regarding College Plans Questions

For the "college plans" questions (Figures 6-8), individual teacher data were evaluated to determine if there were additional trends in student responses. Regarding plans to attend college (Figure 6), the overall percentage shift in student response (pre vs. post) was reported to be 0% for Cohort 2009 and 3% for Cohorts 2010-2013. Considering the individual teacher data, students for three (3) of the 46 teachers demonstrated at least a 20% shift toward favoring plans on going to college. For the other teachers, there was no significant change in student responses.

Considering the number of students planning to enroll in advanced courses (Figure 7), the overall percentage shift was reported as 2% shift towards the "agreement" end of the Likert scale. From the individual teacher data, the changes in student responses (pre vs. post) were minimal for each of the 46 teachers.

When considering engineering as a college major (Figure 8), the overall shift in student response (pre vs. post) was reported to be 8.2% for Cohort 2009 and 7.4% for Cohorts 2010-2013. Investigating the individual teacher data, there were five (5) teachers whose students expressed more than a 30% shift towards increased interest in an engineering major when comparing their survey responses (pre vs. post); there were six (6) teachers whose students expressed a 10%-20% shift towards increased interest. For the remaining 35 teachers, the survey responses were less than a 10% shift in their student responses regarding increased interest in studying engineering.

In their final reports submitted to the E^3 program

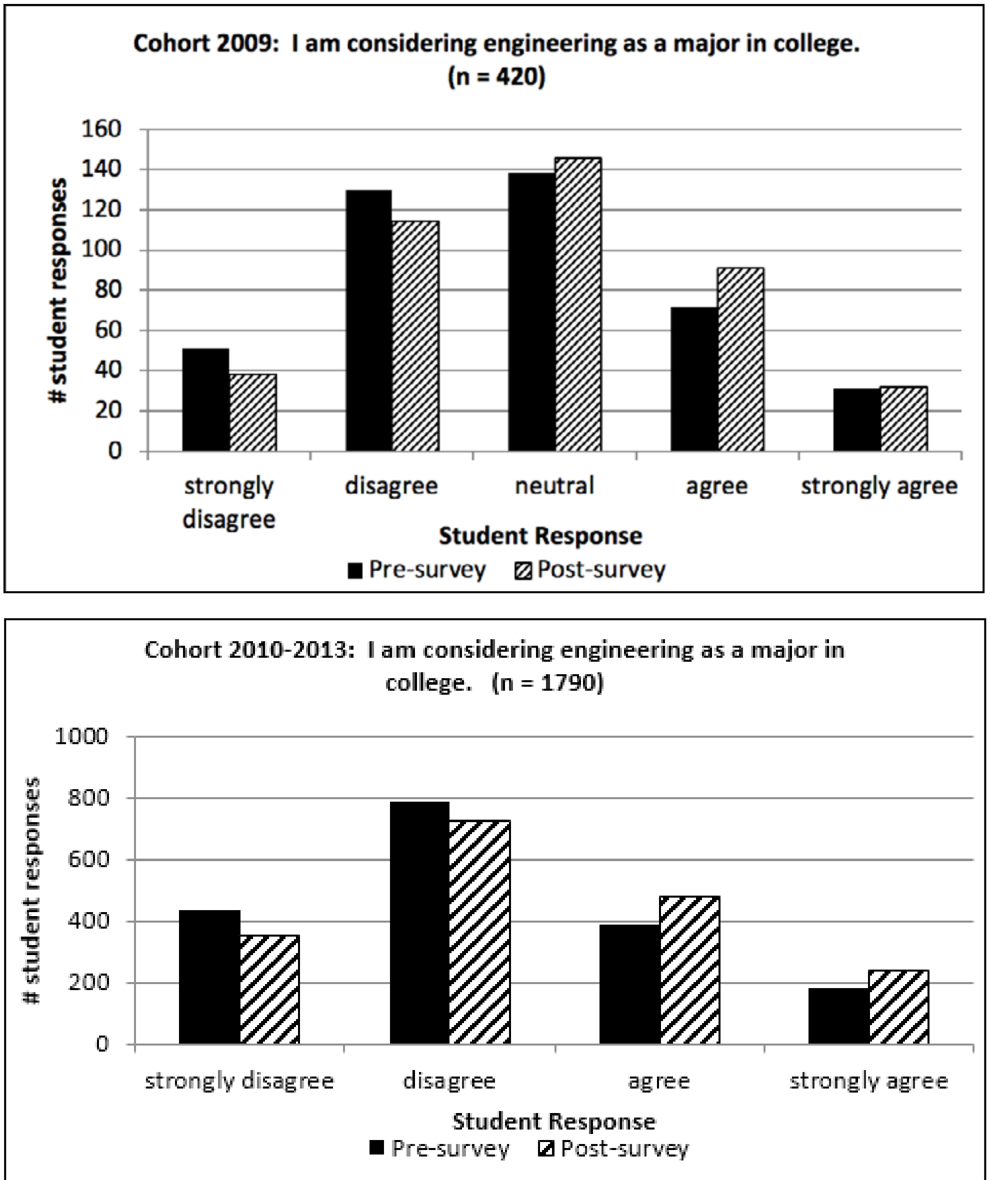


Figure 8 (a & b): Student Pre- and Post-Responses to Question 8

team, virtually all of the teachers expressed receiving positive feedback from the majority of their students regarding the E^3 classroom activities. The overall changes in student responses (pre vs. post) regarding interest in considering an engineering major (Figure 8), demonstrate a positive impact by the teachers. In the pre-survey, 32.4% of the students indicated interest in pursuing an engineering major ("agree" or "strongly agree" responses). In the post-survey, that percentage rose to 40.6%.

What about the other 59.4% of the students surveyed (i.e., those students who "disagreed" or "strongly disagreed") regarding interest in considering an engineering major in college? Perhaps the older students (juniors and seniors) had already decided on another college major to pursue, or had decided not go to college at all. Some of the younger students (freshmen and sophomores) may have the ability and/or interest, but were still reluctant to consider engineering. Of course, many students will never consider engineering because of their perceived lack of ability and/or their lack of interest in engineering for their own pursuits. Since this survey was not part of a study designed to investigate these issues, we can only speculate on the students' reasons behind their responses.

Conclusions

These survey findings are not part of a rigorously designed study, so it is not possible to determine the factors explaining the results. However, this is a large dataset (i.e., survey responses from 2,263 high school students) regarding students' increased awareness of (and interest in) the field of engineering as a result of the implementation of their teacher's engineering-related classroom lessons.

The survey responses (pre vs. post) to questions related to engineering awareness suggest that student awareness was increased following the classroom implementation of E^3 lessons/activities. The student responses to college plans indicated that there was an increased interest in pursuing a college major in engineering.

For those students who already have an interest in engineering, there are K-12 outreach programs available (e.g., summer camps, after-school programs, etc.) to help them decide whether to pursue an engineering career. Unfortunately, the vast majority of students sitting in today's K-12 classrooms have little (or no) awareness of engineering and the rewarding career they might have if they pursued engineering.

The E^3 program, and the student surveys conducted as a part of the program, demonstrate the value in using teachers to expose students to engineering through their math and science classes to create an awareness and attainability for students who might not have considered this career path. It is important to note that even if students do not follow continued studies to prepare for or enroll in engineering, their increased awareness of the field has value in creating an appreciation for the engineering profession. However, implementing surveys to quantitatively or qualitatively assess how many students who had been exposed to the E^3 teachers actually entered a STEM field would provide more evidence of the impact of teaching influence.

Although NSF funding for the E^3 program concluded in August 2013, the TAMU College of Engineering continues to offer this summer program to Texas high school science and mathematics teachers using other sources of financial support.

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References

American Society for Engineering Education (2012). Profiles of engineering and engineering technology colleges. Washington, DC, American Society for Engineering Education.

Autenrieth, R., K. Butler-Purry, C. Page and L. D. Hurtado (2009). Enrichment experiences in engineering (E^3) for teachers summer research program. *American Society of Engineering Education (ASEE) Conference*, Paper No: AC 2009-1108.

Autenrieth, R. L., C. W. Lewis and K. L. Butler-Purry (2017). Long-term impact of the Enrichment Experiences in Engineering (E^3) summer teacher program. *Journal of STEM Education 18*(1): 5-11.

Autenrieth, R. L., C. A. Page, C. L. Lewis and K. Butler-Purry (2014). The Enrichment Experiences in Engineering (E3) summer teacher program: Analysis of post-program surveys. *American Association of Engineering Education Conference*. Indianapolis, IN. Paper ID #9542.

Baker, D. S., S. Krause, C. Kurpius-Robinson, C. Roberts, S. Krause and S. Yasar (2006). A valid and reliable survey instrument for measuring K-12 teachers' perceptions and needs on design, engineering, and technology. *American Society of Engineering Education Conference Proceedings*, 2006-1120.

Blanchard, S., J. Judy, C. Muller, R. H. Crawford, A. J. Petrosino, C. K. White, F.-A. Lin and K. L. Wood (2015) Beyond blackboards: Engaging underserved middle school students in engineering. *Journal of Pre-College Engineering Education Research (J-PEER) 5* DOI: https://doi.org/10.7771/2157-9288.1084.

Bureau of Labor Statistics. (2017). Occupational Outlook Handbook, 2015-16 Edition. Retrieved from https://www.bls.gov/ooh/architecture-and-engineering/home.htm.

Committee on Underrepresented Groups and the Expansion of the Science and Engineering Workforce Pipeline (2010). Expanding underrepresented minority participation: America's science and technology talent at the crossroads. Washington, DC, National Academies Press.

Cunningham, C. and M. Knight (2004). Draw an engineer test: Development of a tool to investigate students' ideas about engineers and engineering. *Proceedings of the 2004 American Society for Engineering Education Annual Conference and Exposition,* Salt Lake City, Utah, ASEE.

Cunningham, C., C. Lachapelle and A. Lindgren-Streicher (2005). Assessing elementary school students conceptions of engineering and technology. *Proceedings of the 2005 American Society for Engineering Education Annual Conference and Exposition*, Portland, OR, ASEE.

Dick, T. P. and S. F. Rallis (1991). Factors and influences on high school students' career choices. *Journal for Research in Mathematics Education 22*(4): 281-292.

Ennis, S. R., M. Rios-Vargas and N. Albert (2011). The Hispanic population: 2010. 2010 Census Briefs. U.S. Census Bureau. Washington, DC. May 2011: 16.

Fadali, M. S. and M. Robinson (2000). How do the National Science Education Standards support the teaching of engineering principles and design?, Kansas City, MO, USA, Stripes Publishing.

Feder, M. (2012). One Decade, One Million more STEM Graduates. from http://www.whitehouse.gov/blog/2012/12/18/one-decade-one-million-more-stem-graduates.

Ferreira, M. M. (2001). The effect of an after-school program addressing the gender and minority achievement gaps in science, mathematics, and engineering. *ERS Spectrum 19*(2): 11-18.

Gibbons, S. J., L. S. Hirsch, H. Kimmel, R. Rockland and J. Bloom (2004). Middle school students' attitudes to and knowledge about engineering. *International Conference on Engineering Education*. Gainesville, FL.

Hoh, Y. K. (2007). Introduction to prominent women in chemical engineering: An outreach activity. *Journal of Women and Minorities in Science and Engineering 13*: 377-390.

Johnson, A., G. Ozogul, M. DiDonato and M. Reisslein (2013). Engineering perceptions of female and male K-12 students: Effects of an animated agent-based overview on elementary, middle, and high school students. *European Journal of Engineering Education 38*(5): 519-531

Lindsley, L. L. and V. A. Burrows (2007). Work in progress - Changes in secondary school teachers' attitudes following a course in engineering design. Frontiers in Education Conference, FIE, 37th ASEE/IEEE *Frontiers in Education Conference.* Piscataway, NJ Institute of Electrical and Electronics Engineers Inc.: 2-12.

Lovencin, W., F. Najafi and N. Safai (2007). A review of strategies employed on minority recruitment and retention in engineering education, Honolulu, HI, United States, *American Society for Engineering Education Conference*, Chantilly, VA 20153, United States.

McCaffrey, D. F., J. R. Lockwood, D. L. Koretz and L. S. Hamilton (2003). Evaluating Value-Added Models for Teacher Accountability. Santa Monica CA, RAND.

Miller, B. M. (2003). Critical hours: After school programs and educational success. Quincy, MA, Nellie Mae Education Foundation.

Montfort, D. B., S. Brown and V. Whritenour (2013) Secondary students' conceptual understanding of engineering as a field. *Journal of Pre-College Engineering Education Research (J-PEER)* 3, Article 2 DOI: https://doi.org/10.7771/2157-9288.1057.

Nathan, M. J., Atwood, M.K., Prevost, M. Phelps, L.A., Tran, N.A., (2011) How professional development in Project Lead the Way changes high school STEM teachers' beliefs about engineering education. *Journal of Pre-College Engineering Education Research 1*, 15-29.

National Academy of Sciences, National Academy of Engineering and Institute of Medicine (2010). Rising above the gathering storm, revisited: Rapidly approaching category 5. Washington, DC, National Academies Press.

National Research Council (1996). National Science Education Standards. Washington, DC, National Academy Press.

National Research Council (2009). Engineering in K12 education: Understanding the status and improving the prospects. Committee on K-12 Engineering Education. L. Katehi, G. Pearson and M. Feder. Washington, DC: 234.

National Research Council (2012). A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas. Washington , DC.

National Research Council, National Science Teachers Association, American Association for the Advancement of Science and Achieve. (2011). Next Generation Science Standards. Retrieved from http://www.nextgenscience.org/.

National Science Board (2014). Science and Engineering Indicators 2014. Arlington VA.

National Science Foundation - National Center for Science and Engineering Statistics (2011). Science and Engineering Degrees: 1966-2008. Detailed Statistical Tables NSF 11-316. Arlington, VA, National Science Foundation.

National Science Foundation - National Center for Science and Engineering Statistics (2015). Science and Engineering Degrees: 1966-2012. Detailed Statistical Tables NSF 15-326. Arlington VA, National Science Foundation.

National Science Foundation. Research Experiences for Teachers in Engineering and Computer Science. from https://www.nsf.gov/funding/pgm_summ.jsp?pims_id=505170.

Neilsen, N., Planning Committee on Evidence on Selected Innovations in Undergraduate STEM Education and National Research Council (2011). Promising practices in undergraduate science, technology, engineering, and mathematics education: Summary of two workshops Washington, DC, National Academies Press.

Nora, A. (2004). 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 3*(2): 180-208.

Northern, J. (2007). Recruitment and retention programs for minorities in engineering programs, Honolulu, HI, United States, *American Society for Engineering Education Conference*, Chantilly, VA 20153, United States.

Nugent, G., B. Barker, N. Grandgenett and V. Adamchuk (2009). The use of digital manipulatives in K-12: Robotics, GPS/GIS and programming. *IEEE International Conference on Frontiers in Education,* San Antonio, TX.

Nye, B., S. Konstantopoulos and L. Hedges (2004). How large are teacher effects? *Educational Evaluation and Policy Analysis 26*(3): 237-257.

Ohland, M. W., C. E. Brawner, M. M. Camacho, R. A. Layton, R. A. Long, S. M. Lord and M. H. Wasburn (2011). Race, gender, and measures of success in engineering education. *Journal of Engineering Education 100*(2): 225-252.

Oware, E., B. Capobianco and H. Diefes-Dux (2007). Gifted students' perceptions of engineers? A study of students in a summer outreach program. *American Society for Engineering Education Conference & Exposition.* Honolulu, HI.

Page, C. A., C. W. Lewis, R. L. Autenrieth and K. L. Butler-Purry (2013). 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 14*(3): 10-16.

Paterson, K. and M. Jarvie (2008). Gender differences in the values of minority high school students that affect engineering discipline choice & recommendations for attracting minorities to engineering. *American Society for Engineering Education Conference*, Pittsburgh, PA.

Pope, M. L. and B. Fermin (2003). The perceptions of college students regarding the factors most influential in their decision to attend postsecondary education. *College & University 78*(4): 19.

President's Council of Advisors on Science and Technology. (2012). Engage to excel: Producing one million additional college graduates with degrees in science, technology, engineering, and mathematics. from https://ccrscenter.org/products-resources/resource-database/engage-excel-producing-one-million-additional-college-graduates.

Project Lead The Way. "Project Lead The Way." from https://www.pltw.org/.

Rivkin, S. G., E. G. Hanuskeh and J. F. Kain (2000). Teachers, Schools, and Academic Achievement. Cambridge, MA, National Bureau of Economic Research NBER Working Paper #W6691.

Rowan, B., R. Correnti and R. J. Miiller (2002). What large-scale research tells us about teacher effects on student achievement: Insights from the Prospects Study of Elementary Schools. *Teachers College Record 104*(8): 1525-1567.

Texas Education Agency. Texas Science, Technology, Engineering and Mathematics Initiative (T-STEM). from https://tea.texas.gov/T-STEM/.

Texas Education Agency. (2010). Texas Essential Knowledge and Skills for Career and Technical Education. from http://ritter.tea.state.tx.us/rules/tac/chapter130/ch130o.html.

Trenor, J. M., S. L. Yu, C. L. Waight, K. S. Zerda and T.-L. Sha (2008). 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 97*(4): 449-465.

U.S. Census Bureau. (2010). 2010 Census Data. Retrieved July 9, 2011, from http://2010.census.gov/2010census/data/.

U.S. Department of Education (2009) Students who study science, technology, engineering, and mathematics (STEM) in postsecondary education. Stats in Brief July, 1-25.

US Department of Labor (2007). 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. Washington, DC.

Van Haneghan, J. P., S. A. Pruet, R. Neal-Waltman and J. M. Harlan (2015) Teacher beliefs about motivating and teaching students to carry out engineering design challenges: Some initial data. *Journal of Pre-College Engineering Education Research (J-PEER) 5* DOI: https://doi.org/10.7771/2157-9288.1097.

Wulf, W. (2002). The Importance of Diversity in Engineering. Diversity in Engineering: Managing the Workforce of the Future. National Research Council, The National Academies Press: 8-15.

Wulf, W. A. and G. M. C. Fisher (2002). A makeover for engineering education. *Issues in Science and Technology:* 35-39.

Yasar, S., D. Baker, S. Sobinson-Kurpius, S. Krause and C. Roberts (2006). Development of a survey to assess K-12 teachers' perceptions of engineers and familiarity with teaching design, engineering, and technology. *Journal of Engineering Education 95*(3): 205-216.

Yilmaz, M., J. H. Ren, S. Custer and J. Coleman (2010). Hands-on summer camp to attract K-12 students to engineering fields. *IEEE Transactions on Education 53*(1): 144-151.

Yoder, B. (2015). Engineering by the Numbers. Washington DC, American Society of Engineering Education.

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APPENDIX

Student Survey Questions

FOR QUESTIONS 1-4, list as many examples as you can (maximum of 10).

1. What engineered devices do you have today that your parents did not have when they were children?

1)____________________ (6) ____________________
2) ____________________ (7) ____________________
3) ____________________ (8) ____________________
4) ____________________ (9) ____________________
5) ____________________ (10) ____________________

TOTAL NUMBER: ________

2. What are some of today's world problems that you think engineers could solve?

1) ____________________ (6) ____________________
2) ____________________ (7) ____________________
3) ____________________ (8) ____________________
4) ____________________ (9) ____________________
5) ____________________ (10) ____________________

TOTAL NUMBER: ________

3. How do engineers make our lives more comfortable? Air conditioning is one example.

1) ____________________ (6) ____________________
2) ____________________ (7) ____________________
3) ____________________ (8) ____________________
4) ____________________ (9) ____________________
5) ____________________ (10) ____________________

TOTAL NUMBER: ________

4. Name as many types of engineering fields that you can think of.

1) ____________________ (6) ____________________
2) ____________________ (7) ____________________
3) ____________________ (8) ____________________
4) ____________________ (9) ____________________
5) ____________________ (10) ____________________

TOTAL NUMBER: ________

QUESTION 5: Which of the following describes an engineer?

a. A person who uses the scientific method to make conclusions based on experimentation.
b. A person who uses math to research phenomena in the natural world.
c. A person who applies science and math to fulfill a need in society.

QUESTION 6: I am planning to go to college.

a. strongly disagree
b. disagree
c. agree
d. strongly agree

QUESTION 7: I am currently enrolled or planning to take advanced level classes (e.g., pre-AP, AP, dual credit, honors) that will prepare me for college.

a. strongly disagree
b. disagree
c. agree
d. strongly agree

QUESTION 8: I am considering engineering as a major in college

a. strongly disagree
b. disagree
c. agree
d. strongly agree