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## **AC 2011-1691: ELEMENTARY STUDENTS' PERCEPTIONS OF ENGINEERS**

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# Elementary Students' Perceptions of Engineers: Using a *Draw-an-Engineer Test* to Evaluate the Impact of Classroom Engineering Experiences and Explicit Engineering Messaging

**Abstract** — This study evaluates pre/post 5<sup>th</sup> grade students' (n=335) perceptions of engineering utilizing an engineering attitudes assessment and a *Draw-an-Engineer Test* (DAET) for two cohorts of students in eight elementary schools taught by engineering Graduate Teaching Fellows. One cohort participated in the program *prior to* the implementation of an explicit messaging intervention based upon the National Academy of Engineering's (NAE) *Changing the Conversation (CTC)* findings, while the other cohort actually received the messaging intervention. Engineering attitudes were measured on two dimensions ("knowledge of engineering as a career" and "interest in engineering") at the beginning and end of the academic year. These results were compared with a qualitative analysis of the *Draw-an-Engineer Test*. The results showed that all students significantly improved on the "knowledge of engineering" dimension over time, with the engineering messaging intervention significantly impacting the girls in the study. The results from the "interest in engineering" construct were more complex. The DAET study revealed that gender of the Graduate Teaching Fellow had significant impacts on the engineers drawn by the girls in the study; girls were more likely to draw a female engineer if they were taught by a female Graduate Teaching Fellow. The collective results of this pilot study imply that the CTC messages make a positive impact on 5<sup>th</sup> grade students' engineering attitudes. Further research with additional cohorts is necessary to replicate and validate the results and tease out interactions with additional factors.

## Introduction & Theoretical Framework

Today's engineering graduates are faced with a more global and rapidly-evolving world. Numerous reports, such as the *Engineer of 2020* and *Gathering above the Rising Storm*, call for a transformation of engineering education that fosters the development of innovation while still maintaining high levels of technical proficiency.<sup>1,2</sup> To maintain economic prominence, we need to produce more innovative engineering graduates. During the past decade, the U.S. has graduated between 60,000 and 70,000 engineering bachelor's degrees per year.<sup>3</sup> Further significant gains in the production of engineers will require increasing the participation of women and our growing minority population, and diversity of perspectives and ideas increases our nation's potential for innovation.<sup>4</sup> Although women and minorities make up over three quarters of the U.S. population, less than 20% of engineering graduates are women and only about 13% are underrepresented minorities.<sup>3</sup>

Engineering is also a pathway for leadership and opportunity. In 2008, 22% of all CEOs in Fortune 500 companies held bachelor's degrees in engineering — more than any other major.<sup>5</sup> Thus, at least two distinct motivations for increasing diversity in engineering inspire us to action: national economic competitiveness and social equity through access to educational opportunity.

To broaden participation in engineering, we must increase both the knowledge of and interest in engineering early and often throughout students' K-12 education. Millions of dollars are spent

every year in an attempt to increase the public understanding of engineering; in 2002, nearly \$400 million dollars was spent on this endeavor.<sup>6</sup> These large expenditures, however, have yet to produce measurable gains in public understanding of engineering. In response to this, the National Academy of Engineering conducted a comprehensive study, *Changing the Conversation*, to: (1) identify a small number of messages likely to improve the public understanding of engineering, (2) test the effectiveness of these messages in a variety of target audiences, and (3) disseminate the results of the message testing to the engineering community.<sup>7</sup> As part of the study, the Committee on the Public Understanding of Engineering Messages developed a new positioning statement for engineering:

No profession unleashes the spirit of innovation like engineering. From research to real-world applications, engineers constantly discover how to improve our lives by creating bold new solutions that connect science to life in unexpected, forward-thinking ways. Few professions turn so many ideas into so many realities. Few have such a direct and positive effect on people's everyday lives. We are counting on engineers and their imaginations to help us meet the needs of the 21<sup>st</sup> century.<sup>7</sup>

Responding to the need for broader participation in and awareness of engineering, the University of Colorado Boulder created the TEAMS (T**o**morrow's E**n**gineers... cre**A**te. i**M**agine. S**u**cced.) Program, a long-range university/public school district partnership to bring engineering and its opportunities to K-12 students, regardless of circumstance, with the goal of specifically broadening participation from populations underrepresented in engineering — girls, students of color and first-generation college bound youth. As part of this partnership, engineering TEAMS Fellows teach in-class, hands-on engineering activities and lessons designed to help K-12 students: (1) understand the role that engineers play in meeting the needs and dreams of society, (2) draw connections to meaningful applications of science, math and technology, and (3) become motivated to create a bright future for themselves through engineering and technology. For a detailed description of the TEAMS program, see Zarske et al. (2007).<sup>8</sup>

Following the release NAE's *Changing the Conversation* study, the TEAMS program began implementing explicit engineering messaging training strategies, such as a presentation on the role engineers play in improving society and highlighting the use of creativity and imagination. The explicit messaging incorporated the four engineering messages that CTC identified as appealing and effective: "*engineers make a world of difference*"; "*engineers are creative problem solvers*"; "*engineers help shape the future*"; "*engineering is essential to our health, happiness and safety.*"

This study evaluates 5<sup>th</sup> grade students' perceptions of engineering for two cohorts of students to address the following three research questions:

- Does program participation impact student attitudes about engineering?
- Did the CTC messaging interventions impact student attitudes about engineering?
- Do messaging interventions or program participation have differential gender impacts?

The DAET was adapted from a long history of methodologies used to investigate public images of science and scientists. Mead and Mètraux (1957)<sup>9</sup> conducted the seminal study of American

children's images of a scientist by qualitatively analyzing essays from 1,000 high school students, asking students to write essays about their views of scientists. As an indicator of how far the field of STEM education has come since that 1957 study, it is interesting to note that girls were asked, "If I were going to marry a scientist, I should like to marry the kind of scientist who..." rather than asking what type of scientist *they* would like to be themselves. Mead et al found that students held a common image of a scientist as "*a man who wears a white coat and works in a laboratory. He is elderly or middle aged and wearing glasses.*" High school students thought the goals of science were dichotomous, either "humanitarian" or "individualistic" and "destructive." The gendered results found in 1957<sup>9</sup> are consistent with results from NAE's<sup>7</sup> contemporary study of appealing engineering messaging.

"The boys, when they react positively, include motives which do not appeal to the girls: adventure, space travel, delight in speed and propulsion; the girls, when they react positively, emphasize humanitarianism and self-sacrifice for humanity, which do not appeal to the boys."

These results have become known as the stereotypical image of a scientist and have been found to be remarkably persistent throughout the years. Chambers (1983) was the first to ask students to *draw* a scientist, which led to decades of study using a *Draw-a-Scientist Test (DAST)* methodology.<sup>10,11</sup> Knight and Cunningham (2004) were the first researchers to convert the DAST methodology to engineering, and since there have been multiple studies in the engineering domain as well.<sup>12-16</sup> This study adds to this rich literature base by explicitly evaluating an intervention implementing CTC's engineering messaging.

## Methods

*Participants* — Attitude surveys and a DAET were given to two cohorts of 5<sup>th</sup> grade students (n=335). Only students who completed both the pre and post surveys were included in the study. The first cohort data was collected during the 2006-2007 academic year in six classes at three public elementary schools in Lafayette, CO. During 2006-2007, the year *prior* to explicit CTC messaging being included as an overt program component, 106 students were included (53 boys and 52 girls), and were taught by two engineering TEAMS Fellows, one female and one male. The second cohort data was collected during the 2009-2010 academic year in 16 classes at five elementary schools in Longmont, CO. That year, 229 5<sup>th</sup> grade students participated in the study (113 boys and 108 girls), and were taught by a single male TEAMS Fellow. Since archival data was used, the nine surveys with missing gender were included in the overall analysis but left out of the gender analysis.

*Assessments* — The attitude survey tested two constructs: "*knowledge of engineering*" and "*interest in engineering.*" Both scales were created to assess interest and knowledge of students in a fashion similar to attitude tests found in the *Assessing Women and Men in Engineering (AWE)* study.<sup>17</sup> The *knowledge of engineering* subscale consisted of six items ( $\alpha = .66$ ), and the *interest in engineering* subscale consisted of seven items ( $\alpha = .61$ ). All students participating in the program rate their level of interest in engineering and confidence in their knowledge of engineering as a career. Students rate their attitudes on five-point Likert-type scales, with 5 equal to "definitely interested." At the end of the survey, students are asked to name one thing invented

by an engineer and to draw a picture of what they think an engineer looks like. Students were given the pre survey in the fall near the beginning of their participation in the TEAMS program and again at the end of the spring semester. Surveys for elementary students used age-appropriate terms, and questions were read out loud by the Fellow to the students.

*Study Design and Coding* — This study employed a mixed-method design to evaluate pre/post 5<sup>th</sup> grade students' perceptions of engineering. The first cohort experienced the in-class engineering instruction *prior to* the messaging intervention, and the second cohort received the *Changing the Conversation* messaging intervention *as part of* their in-class instruction.

In the quantitative component of the study, a 2 x 2 study design was employed to test both the impact of the overall program (pre, post) and the messaging intervention impact on students' perceptions of engineering (cohort 1, cohort 2). Since the driving goal of the K-12 engineering education program is to broaden participation and access to engineering, gender differences were assessed for each measure. Attitude measures, knowledge and interest, and gender interactions were analyzed using repeated measures ANOVA tests.

In the qualitative component of the study, results from the *Draw-an-Engineer Test* were coded using open-coding techniques.<sup>18</sup> In the first round of coding, a binary coding system was used to code for the presence of a person in each student drawing. If a drawing contained a person, gender was coded as male, female or undetermined. Each drawing was also coded for things present in the picture: presence of an action occurring, characteristics of engineers (if present) and characteristics of the environment (if present). The initial round of coding was conducted by one coder. To establish reliability, a second coder evaluated and coded a 10% random sample of the second cohort. This reliability test identified inconsistencies in gender coding, with a bias towards coding undeterminable gender as male drawings. The two coders worked together until they achieved consistency and then recoded the entire two-cohort data corpus.

The following results section first presents the results of the quantitative analysis and gender differences of both attitude measures, followed by the results from the qualitative *Draw-an-Engineer Test*. These results are followed by a discussion of the collective results and the educational implications of the study.

## Results

*Engineering Attitudes* — We found a main effect of CTC messaging (by cohort) for both *knowledge* of engineering as a career and *interest* in engineering. On the *knowledge* of engineering measure, there was a significant interaction effect as the 2009-2010 cohort out-gained the 2006-2007 cohort that participated prior to explicit CTC messaging. On the *knowledge* measure, there was a stronger impact on girls, but a non-significant impact on boys.

The second cohort increased significantly on the *interest* measure, while the first cohort decreased, resulting in a significant interaction effect. However, gender analysis revealed that the impact on engineering *interest* was only significant for boys. Girls in the post-messaging cohort improved, but the pre-messaging cohort was statistically flat. These results are discussed in more detail later.

The *knowledge* of engineering as a career and *interest* in engineering scores were analyzed using a 2 x 2 repeated measures ANOVA on each measure with year (Year 1, 2) as the between-subjects factor as a proxy for the pre-/post-messaging intervention and time (pre, post) as the within-subjects factor. For both measures, each cohort was analyzed by gender using a 2 x 2 repeated measures ANOVA with year (Year 1, 2) as the between-subjects factor and time (pre, post) as the within-subjects factor.

*Knowledge of Engineering as a Career* — We found that all students in both cohorts improved significantly over time in their knowledge measure ( $p < .05$ ), with the second cohort (14% gain) out-gaining the pre-messaging first cohort (7% gain; see Figure 1). However, the pre-messaging cohort both started and ended higher on the *knowledge* of engineering measure,  $M=4.69$ ,  $STD=0.37$ , compared to  $M=4.53$ ,  $STD=0.45$ .

We also found a significant interaction effect for girls ( $p < .05$ ), with the pre-messaging cohort outperforming the post-messaging cohort on both the pre and post tests; however, the post-messaging cohort out gained the first cohort, a 17% gain compared to 6% gain for the pre-messaging cohort (see Figure 2.) Similarly, the pre-messaging cohort out-performed the post-messaging cohort with similar gains (10% compared to 12%) so the difference was not statistically significant.

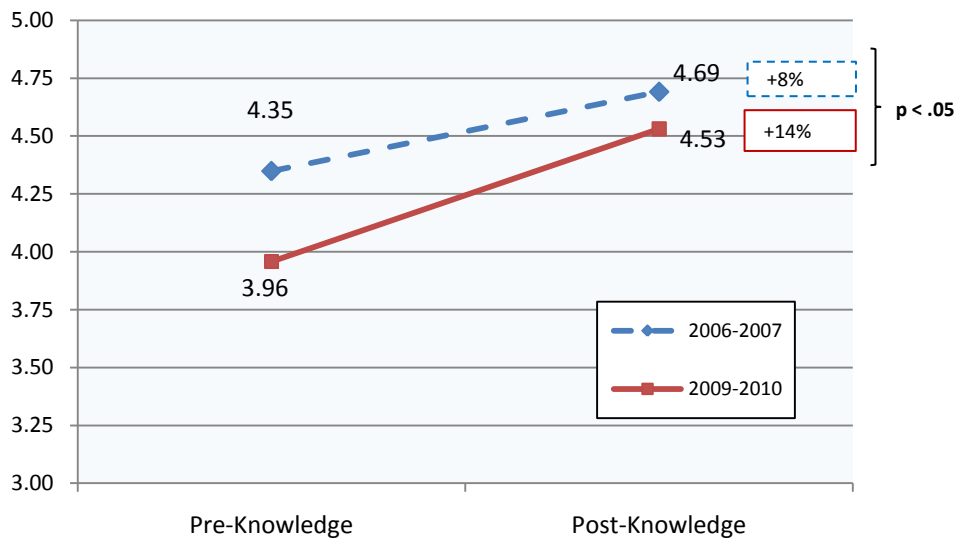


Figure 1. Gains in knowledge of engineering as a career, cohort 1 (2006-2007) compared to cohort 2 (2009-2010).

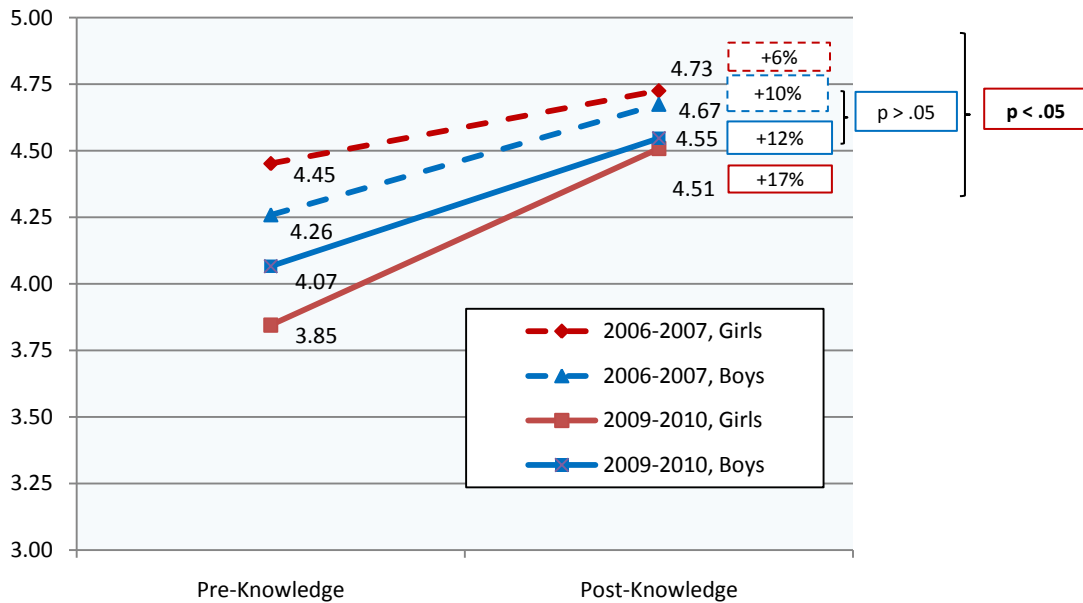


Figure 2. Gains in knowledge of engineering as a career by gender, cohort 1 (2006-2007) compared to cohort 2 (2009-2010).

*Interest in Engineering as a Career* — The results for interest in engineering as a career tell a different story. Overall, the second cohort expressed more interest in engineering at both the pre and post tests, indicating that participation in the elementary engineering program increased interest in the engineering for the post-messaging cohort. However, as shown in Figure 3, interest in engineering *decreased* on the post survey for the first cohort, resulting in an overall messaging interaction effect ( $p < .05$ ).

Boys' performance mirrored the overall performance ( $p < .05$ ; see Figure 4). Although the girls in the post-messaging cohort out-performed the pre-messaging cohort whose pre/post scores were statistically flat, this interaction was not significant. The girls in the post-messaging group increased, with a pre-/post-t-test resulting in a significant difference ( $p < .05$ ). Further analysis with additional cohorts is necessary to increase statistical power and explore these differences.

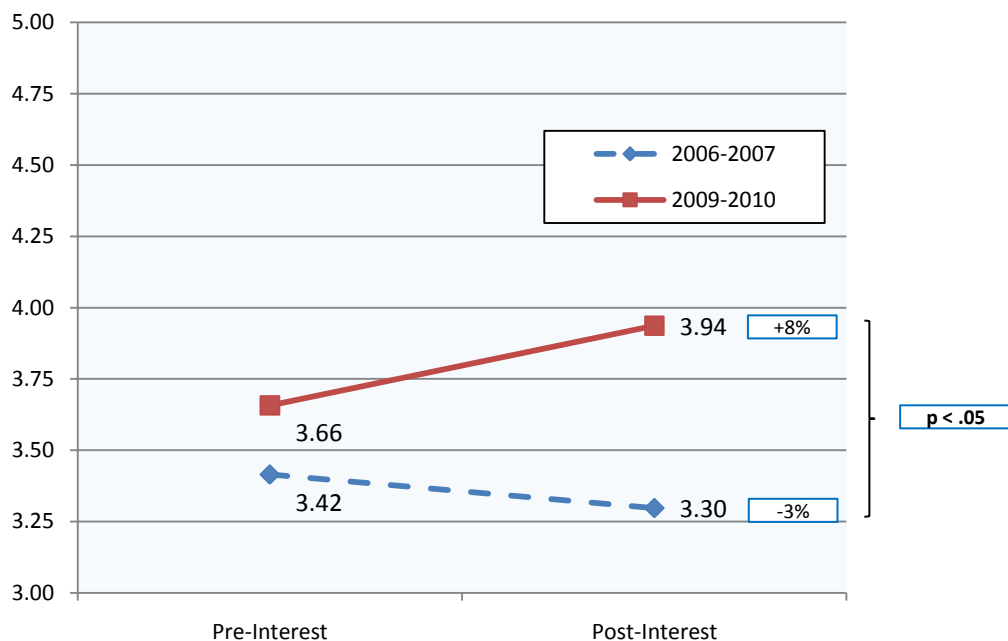


Figure 3. Changes in *interest* in engineering as a career, cohort 1 (2006-2007) compared to cohort 2 (2009-2010).

*Draw-an-Engineer Test (DAET)* — Approximately 10% of the DAET tests showed images of an *object* instead of an engineer, with gender indiscernible in 30% of images containing a person. Of interest is that only three boys in the entire sample drew a female engineer — suggesting that societal bias towards *who belongs* in the engineering profession is established early. In all the girls’ drawings that included an image with discernible gender (including pre and post instances), 37% percent of their drawings included a female engineer. Table 1 shows the percent gains by gender for each cohort. To our surprise, the girls in pre-CTC messaging cohort (2006-2007) drew more female engineers than the post-messaging cohort (2009-2010), with an 11% gain in the pre-messaging cohort and a 4% decrease of female drawings in the post-messaging cohort. However, further analysis revealed the gender of the TEAMS Fellow made a significant difference in the number of female engineers drawn by girls in the study.

Many of the students drew pictures of the teaching Fellow in their classroom as their idea of who an engineer is. Figure 5 shows students’ examples, with both drawings showing the Fellows wearing the program-branded shirts that each Fellow was required to wear while teaching in the classroom.

In the 2006-2007 cohort, two TEAMS Fellows, one female and one male, taught five 5<sup>th</sup> grade classes. In the 2009-2010 cohort, all of the 5<sup>th</sup> grade classes were taught by a single male Fellow. Thus, only the 2006-2007 cohort was analyzed by gender of the Fellow. On the post assessment, 81% of the girls taught by a female Fellow drew a female engineer, compared to 41% of the girls taught by a male Fellow (see Figure 6).



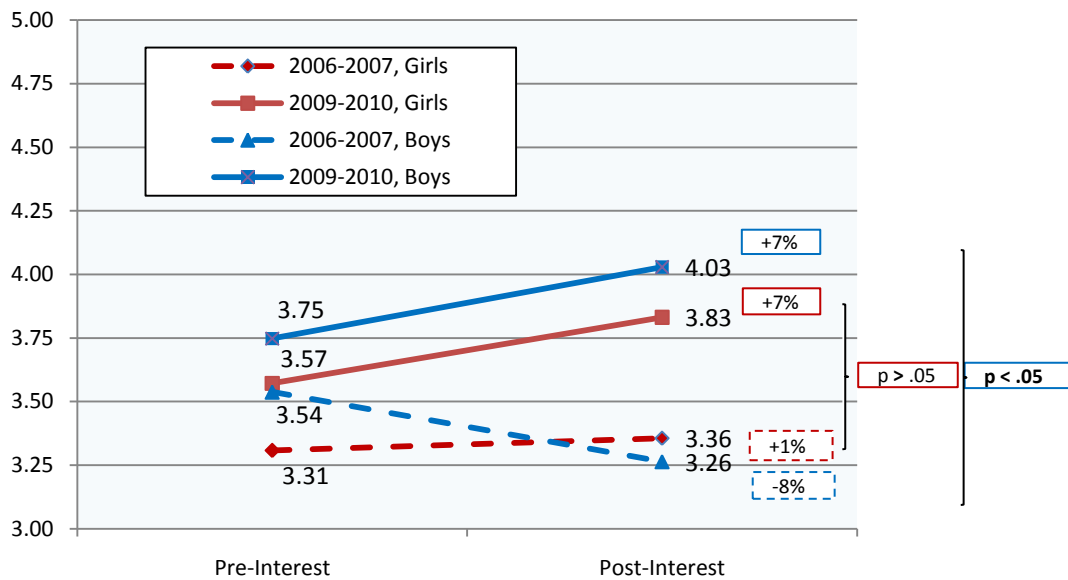


Figure 4. Gains in interest in engineering by gender, 2006-2007 compared to 2009-2010.

Table 1. Draw-An-Engineer Percent Gain Results

| Year      | Time | Girls' Drawings |        |      |        |         |
|-----------|------|-----------------|--------|------|--------|---------|
|           |      | N               | Person | Male | Female | Neutral |
| 2006-2007 | Pre  | 55              | 96%    | 38%  | 57%    | 8%      |
|           | Post | 44              | 98%    | 19%  | 67%    | 14%     |
|           | Gain |                 | 1%     | -19% | 11%    | 6%      |
| 2009-2010 | Pre  | 78              | 92%    | 51%  | 19%    | 24%     |
|           | Post | 78              | 83%    | 42%  | 15%    | 27%     |
|           | Gain |                 | -9%    | -9%  | -4%    | 3%      |
| Year      | Time | Boys' Drawings  |        |      |        |         |
|           |      | N               | Person | Male | Female | Neutral |
| 2006-2007 | Pre  | 52              | 92%    | 71%  | 2%     | 27%     |
|           | Post | 45              | 91%    | 71%  | 2%     | 27%     |
|           | Gain |                 | -1%    | 0%   | 0%     | 0%      |
| 2009-2010 | Pre  | 93              | 92%    | 60%  | 1%     | 43%     |
|           | Post | 68              | 82%    | 43%  | 0%     | 38%     |
|           | Gain |                 | -10%   | -18% | -1%    | -5%     |



Figure 5. Example DAET drawings. TEAMS Fellows are shown as engineers, as evidenced by the program-branded shirts worn by Fellows while teaching.

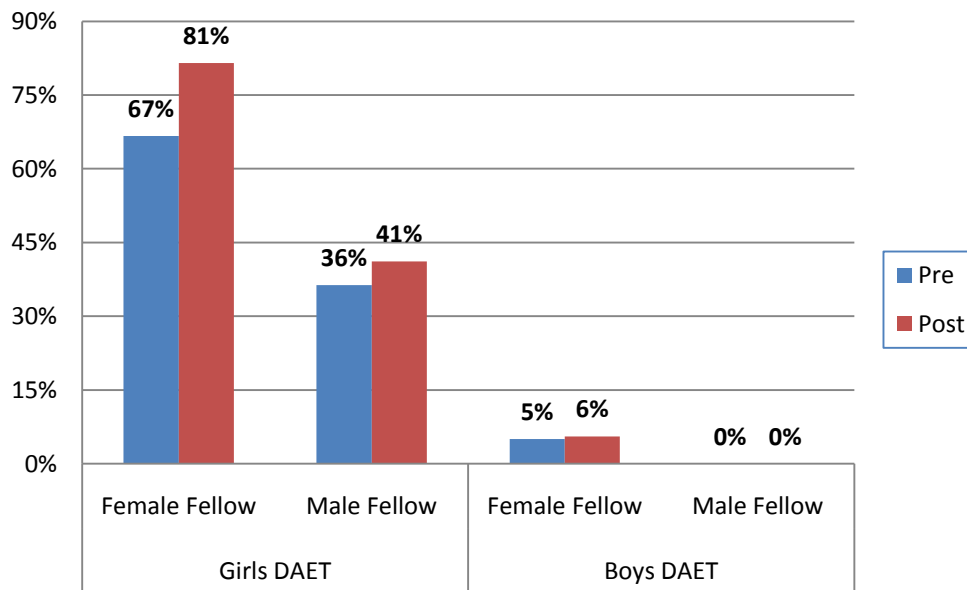


Figure 6. Cohort 1 drawings of female engineers by Fellow gender.

### Discussion and Educational Implications

This pilot study is the first attempt to evaluate the classroom impact of the CTC messaging recommendations. The marketing studies commissioned by the NAE Committee on Public Understanding of Engineering Messages were comprehensive, but the complexity of classroom learning can often yield different results than studies completed in non-classroom conditions.

The elementary engineering program effectively increased boys and girls knowledge of engineering as a career, as both genders in both cohorts increased their knowledge of

engineering. Even though cohort 1 had higher *knowledge* of engineering scores across the board, the CTC messaging was still significant because the messaging cohort out-gained the pre-messaging cohort. Study limitations could have contributed to the pre-test differences of all the constructs. The 2006-2007 pre-messaging cohort participated in the seventh year of the program in the Lafayette school district, suggesting, perhaps, that their knowledge was already high on the pre-test due to an accumulated learning effect from previous years in the program; whereas, the 2009-2010 cohort participated in the first year of a new program in an expansion school district in Longmont.

The qualitative analysis of the *Draw-an-Engineer Test* drawings did not show any messaging intervention differences. However, definite gender differences were discovered in the number of female engineers drawn— with a significantly larger number of female images (37%) than most of the previous research. Historically, very few students draw female engineers or scientists. In the original Draw-a-Scientist study, only 18 of 4,807 students (less than 1%) in grades K-5 drew female scientists, and in 1989 in a replication study, 165 of 1,600 2<sup>nd</sup>-12<sup>th</sup> grade students (10%) drew female scientists.<sup>10,19</sup> In engineering, and in contrast to our study, only one of 19 (5%) of the 6<sup>th</sup> graders in Karatas, Micklos, and Bodner's (2010) qualitative study drew a female engineer.<sup>15</sup>

Our results are consistent with those found in Knight and Cunningham's (2004) study of the images of engineers.<sup>12</sup> Of the 64 gender discernible drawings in their study, 39% were drawings of women engineers while 49% of the 25 girls drew women engineers. The authors attributed this unusually high number to the fact that "most of these drawings were from a classroom in which two female undergraduate engineering students ... had been working with the students for a few months before the survey was given." Since we were investigating the effects of our CTC messaging intervention, Fellow gender was not a variable included in the initial design of the study—it was subsequently added as an unanticipated result of the qualitative analysis of the DAET images.

Knight and Cunningham (2004) used female role models in the classroom to explain the "unusually high" number of images of female engineers in their study. Since they had *only* female engineering role models in their study, they did not analyze for a gender effect. Our analysis showed that having a female role model *significantly increased* the number of female engineers drawn by the girls in the study. We believe Fellow gender *might be as important* in impacting students' perceptions about engineering as are the efforts of explicit messaging. We are qualifying this conclusion because of our sample size; only 27 girls in our sample of 335 students actually had a female role model in their classroom. However, future research will address this question, as we are currently analyzing student images in additional cohorts to increase the sample size and allow for further analysis of interaction effects.

The collective results of the quantitative attitudes assessment and the qualitative analysis of the DAET drawings imply that the NAE's CTC messaging can make a positive impact on 5<sup>th</sup> grade students' attitudes about engineering. However, classroom research limitations introduced additional uncontrolled factors such as Fellow gender and years in the program into the study. Thus, further work with additional cohorts is necessary to replicate and validate these results and tease out interactions with additional factors. Future longitudinal studies are necessary to

ultimately answer the question as to whether or not explicit CTC messaging at a young age is making the desired impact of increasing diversity in college engineering enrollment.

### Acknowledgements

The authors gratefully acknowledge the support of the National Science Foundation for Track 2 GK-12 grant no. 0338326 and Track 3 GK-12 grant no. 1133773. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation. We also acknowledge additional support provided by the University of Colorado Undergraduate Research Opportunities Program. Alexander Archuleta and Linda Rivera Palacios, both undergraduate research students, made substantial contributions to this study in the qualitative coding of the *Draw-an-Engineer* data.

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