2006-1981: INVESTIGATING THE LONG-TERM IMPACT OF AN ENGINEERING-BASED GK-12 PROGRAM ON STUDENTS' PERCEPTIONS OF ENGINEERING

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Investigating The Long-Term Impact of an Engineering-Based GK-12 Program on Students' Perceptions of Engineering

Abstract

This paper investigates the long-term impact of an engineering-based GK-12 program on students' perceptions of engineering. Student attitudes towards science, technology, engineering and math (STEM) disciplines and the resulting influence they have on career interests in these fields are a major concern of current K-12 education reform efforts. These reform efforts stress that scientists and engineers need to take part in science and technological education at all levels. Supporting reform documents further advocate that simple involvement is not sufficient and that collaboration between scientists, engineers and K-12 teachers needs to be focused on the teacher's curriculum and take place in the K-12 classroom.

In the 1990s the National Science Foundation (NSF) introduced the Graduate Teaching Fellows in K-12 Education (GK-12) initiative, designed to support the participation of graduate students from STEM disciplines in K-12 science and math education. In GK-12 projects, STEM graduate students spend 15-20 hours a week over an academic year serving as resources for K-12 science and math teachers. This study focuses on a GK-12 project that paired graduate engineering and computer science students called Engineering Fellows (Fellows) with upper elementary science teachers. Fellows and teachers worked in yearlong partnerships co-developing and co-teaching student lessons focused on engineering examples, design approaches and problem solving techniques to show the application of science, technology and mathematics concepts.

Over 3 academic years, upper elementary and middle school science and math teachers (grades 3-8) were partnered with Fellows. To measure perceptions of engineering, students were asked to draw a pre/post picture of an engineer working and write a story describing the action that was occurring in the drawing as well as take part in interviews focused on this work. A team of graduate engineering students and educational researchers developed a numerical coding system that was used to score student work and additional open-ended analysis of student interview data was completed.

Initial research on students in Fellows' classes demonstrated that the Engineering Fellow students made statistically significant gains in their understandings of engineering when measured annually pre to post. These students were more likely to portray an engineer as a designer, to better understand engineering processes, the diversity of fields represented by the term engineering and the work typically done within engineering fields.

To capture the long-term influence of interaction with a Fellow, similar follow-up data were collected from a subset of project students and a control group of students the year following this 3-year engagement. The majority of project students held clearer

perceptions of engineers and the work they do. Further, interview data suggests that a substantial portion of these students attributed their engineering understandings to previous exposure to a Fellow in elementary school. These findings, and the resulting implications, will be discussed in detail during this paper and presentation.

Introduction

This paper examines change in students' views of engineering sciences as a result of extended collaborations with graduate students from the engineering sciences. Despite efforts to increase student interest in science, technology, engineering and math (STEM) fields, the number of United States citizens choosing careers in STEM disciplines is declining[1]. This trend is apparent across the general population as well as with underrepresented minority groups[2].

This lack of participation in STEM fields by such a large segment of the general population is an issue of critical importance, especially in light of our country's advancing reliance on technology. These issues arise at the same time that the importance of STEM fields on national prosperity and security are becoming increasingly evident[3]. This leads to a series of questions related to why United States citizens are not choosing careers in STEM disciplines and what can be done to address the underlying issues that create this situation.

Literature

Many of the attitudes that adults have toward science and math are formed during elementary school and carried into adolescence and adulthood. Even though elementary students' attitudes towards science and math are generally positive, their perceptions of scientists and engineers, and the work they do, are generally inaccurate[4]. These perceptions can influence students' selection of academic coursework throughout schooling, having a direct impact on student career opportunities[5]. The perceptions that are developed in elementary school then, result in fewer citizens opting for STEM careers. This paper investigates this issue of inaccurate perceptions and examines a collaboration type that appears to have a positive influence on student perceptions of one STEM discipline, the engineering sciences.

In the 1990s the National Science Foundation (NSF) introduced the Graduate Teaching Fellows in K-12 Education (GK-12) initiative which supports the participation of graduate students from STEM disciplines in K-12 science and math education. In GK-12 projects, STEM graduate students spend 20 hours a week over an academic year serving as resources for K-12 science and math teachers. This study focuses one GK-12 project, the Engineering Fellows Program, which paired graduate engineering and computer science students called Engineering Fellows (Fellows) with upper elementary and middle school science teachers. The Fellows and teachers worked twenty hours a week in yearlong partnerships co-developing and co-teaching student lessons focused on engineering examples, design approaches and problem solving techniques to show the application of science, technology and mathematics concepts.

To capture student perceptions of engineering a "Draw-an-Engineer" instrument was employed. The instrument obtains its theoretical support from the extensive use of drawings by children to capture understandings and perceptions in many settings and fields that are otherwise difficult to ascertain[6, 7, and 8]. One of the most well known of these instruments comes from the field of science, using students' drawings to reveal their perceptions of scientists and what it is they think scientists do[9, 10, and] 11. Similarly, the work reported in this paper compares students' perceptions of the work engineers do to determine if student perceptions of engineering were altered as a result of participation in the Engineering Fellows Program.

Over 3 academic years, upper elementary and middle school science and math teachers (grades 3-8) participated in the Engineering Fellows Program. Each year a pre/post Draw an Engineer instrument was employed to capture students' perceptions of engineering. Analysis of these data revealed that project participation enhanced students' understanding of engineering across four domains[12, 13]. To determine if these changes in perceptions were significantly different than those held by non-project students a follow-up, comparison study was conducted. This study is described below.

Methods

Following the 3 year engagement, all the sixth grade students in a large urban middle school were asked to draw a picture of engineer working and write a story explaining the action that was occurring in the drawings. This population included students who had previously worked in the Engineering Fellows program as well as some who had not. All of these students attended elementary schools that were matched using common School Report Card criteria. A control group of one hundred and twenty-two students and a project group of forty-four students was established based on those students from whom informed consent could be obtained.

Following the completion of the drawings and stories, ten students from each group participated in follow-up interviews. The interviews were conducted to determine the accuracy of rater interpretations of student perceptions of engineering, to establish factors that influenced students' ideas about engineers and engineering, and to identify themes in student perceptions that weren't captured by their work samples.

Design and Procedures

Students were asked by their teachers to draw a picture of an engineer working and write a story describing what was happening in the picture. Directions were read to the students and also provided in writing. Students were told that if they didn't know what an engineer did, they were to write, "I don't know" on the paper and draw anything they liked. Students were then given as much time as needed to complete the drawings.

A team of engineers and educational researchers developed an instrument to score student work called the Draw an Engineering Scoring Guide (Scoring Guide) based on an earlier instrument used for similar purposes called the Draw an Engineer Checklist[14]. This Scoring Guide uses a numerical coding system to score students' drawings and written descriptions. Points were allocated based on the number of drawing artifacts and student descriptions that could be placed within the following four thematic groups: "Engineering Artifacts," "Diversity of Fields," "Engineering Processes," and "Portrayals of Engineering". Drawings that included the text, "I don't know" were assigned zero scores in each category. The sum of all four items (maximum possible score 10), as well as scores from each category were then used as an initial assessment of students' perceptions of engineering. The descriptions provided in Table 1 were the criteria used to determine point totals on student work.

Table 1. Draw an Engineer Scoring Guide

Engineering Artifacts (Tools/Equipment/Models/Symbols)		
0	**1**	**2**
Any of the following found: - I don't know response - No engineering artifacts in picture - No accurate description of engineering artifact	Any of the following found: - Artifacts or description associated with building equipment (hammer, screwdriver) that fits into a typical toolbox - Artifacts or description associated with equipment used for construction (Bull Dozer) - Artifacts or description associated with "testing" typically done by a technician, mechanic or repairman (diagnosing a known problem)	Any of the following found: - Artifacts or description associated with designing and/or model construction (computers, drawing instruments, etc.) - Artifacts or description associated with presenting information or sharing ideas (computers, symbols, formulas, blueprints, models etc.) - Artifacts or description associated with "experimentation" (finding a solution to a given problem)
Diversity of Fields		
0	**1**	**2**
Any of the following found: - I don't know - No engineering fields described or in picture	Single engineering field is portrayed. Artifacts or description representative of one engineering field is apparent (e.g., electric lines or rockets). An accurate portrayal/description of the work typically done within the field is included	Multiple engineering fields are portrayed. Artifacts or description representative of several engineering fields are portrayed (e.g., electric lines and rockets). An accurate portrayal/description of the work typically done within the fields is included

Table 1. Draw an Engineer Scoring Guide continued

Engineering Processes			
0	**1**	**2**	**3**
Any of the following found: - I don't know - No engineering processes apparent in picture or description	- Physical processes associated with engineering being portrayed and/or described. Ex. Fix/Repair Construct Build/Make/Product Realization - Processes associated with verification or confirmation testing being portrayed and/or described. Ex. Confirmation experiment or test. Diagnose a known problem.	- Mental process associated with engineering being portrayed and/or described Ex. Create Design Invent Improve a product Redesign Share or present information Make better - Processes associated with solving an original problem portrayed and/or described. Ex. Primary experiment or Test. Find an original solution to a problem. Collaborate Research	Multiple processes portrayed and/or described, including at least one mental process.
Portrayals of Engineers			
0	**1**	**2**	**3**
"I don't know"	Engineer depicted and/or described as a driver or operator of machinery	Engineer depicted and/or described as a builder/repairman/technician	Engineer depicted and/or described as an inventor/creator/designer/problem-solver/experimenter

Analysis

To develop the Scoring Guide a group of engineering graduate students completed the draw an engineer task. After a series of content analysis on those drawings and consultations with engineers and the engineering graduate students, major themes across all drawings were identified. From this work, an initial scoring guide instrument was developed. Two raters then used this instrument to score 32 drawings from upper elementary students who were not the subjects of this research. This scoring, along with further consultation with the raters, engineers, and engineering graduate students, resulted in the final version of the Scoring Guide instrument used in this research.

To determine the validity of the Scoring Guide, another group of graduate level engineering students completed the draw an engineer task. Their drawings were then scored using the Scoring Guide. Based on the notions that advanced graduate engineering students have accurate perceptions of engineering and the Scoring Guide is an accurate tool to measure perceptions of engineering, high scores from these engineering students indicated that the Scoring Guide was a valid instrument for measuring perceptions of engineering.

Scoring

Three raters completed all scoring of student work samples. Two of the raters were former Engineering Fellows and one was a sixth grade teacher who had not worked in the Engineering Fellows program. The raters participated in a series of training sessions using the Scoring Guide and seed papers. Raters worked to resolve issues associated with the Scoring Guide until a high degree of confidence in the instrument, as well as a high degree of inter-rater reliability, was established.

The raters then scored a total of one hundred and sixty-six student work samples. Pre/post descriptive statistics were calculated and used to determine the degree to which these two student groups differed in their perceptions of engineering. Interview data were also analyzed and used to determine the accuracy of the raters' interpretations of student drawings using the Scoring Guide instrument as well as to identify other themes apparent in student perceptions of engineering not captured by the Scoring Guide. Using the Generalizability theory, the inter-rater reliability estimates were found to be .88946 (Engineering Artifacts and Diversity of Fields), .94564 (Engineering Processes), and .95114 (Engineering Portrayals). The author completed additional open-ended analyses that focused on identifying emerging themes in student work samples and interview statements. This open-ended analysis is included in the discussion of results.

Results

As a result of working with a Fellow during elementary school, project students developed clearer perceptions of engineering. Substantial mean differences were found across all categories of the Scoring Guide, indicating a general difference between groups in terms of their understanding of engineering (See Table 2).

Table 2. Scoring Guide Mean Differences

Category	**Mean Difference**	**Standard Error**
Artifacts	.252	.083
Fields	.314	.082
Processes	.428	.094
Portrayals	.755	.165
Total	.437	.101

Further, an independent samples t-test revealed that participation in the Engineering Fellows program produced significantly better overall (Total) understanding of engineering, $t, (164) = 4.31, p < .05$ (two-tailed). Change in student perceptions of engineering across the individual Checklist categories is discussed below.

Artifacts

Project students portrayed and described significantly more engineering artifacts than did control group students, $t, (164) = 3.029, p < .05$ (two-tailed). Not only were more engineering artifacts displayed and described by project students, their work samples contained more engineering artifacts that involved mental work and higher order thinking. These included greater numbers of design artifacts such as drafting tables, computers, symbols, formulas, blueprints, and models than were found in control group work samples. Overall, 18% of project student work samples included these types of artifacts or referenced their use during engineering work. This is contrasted with 4% of control group work samples that included or referenced similar types of artifacts.

In addition to greater numbers of design artifacts, project work samples were more likely to describe and/or show engineers using these artifacts to present information or share ideas. Fourteen percent of project student work samples portrayed engineers engaged in these practices. Only one similar portrayal was found in control group work samples. Project student understanding of the collaborative nature of engineering can also be seen in the ways that students portrayed engineers working. Twenty percent of project student work samples portrayed engineers working with others while only 8% of control group work samples contained similar portrayals.

The final artifact theme that was apparent in project student work samples focused on "experimentation" (finding a solution to a given problem, product testing, problem diagnosis, research) in engineering work. Artifacts or descriptions associated with experimentation were found in 16% of project student work samples. Similar portrayals were found in less than 1% of control group work samples. Figure 1 is a work sample that captures the type of understanding displayed by project students related to this theme.

3. Describe what is happening in your drawing on the lines below. You may use the back of the page if you need more room.

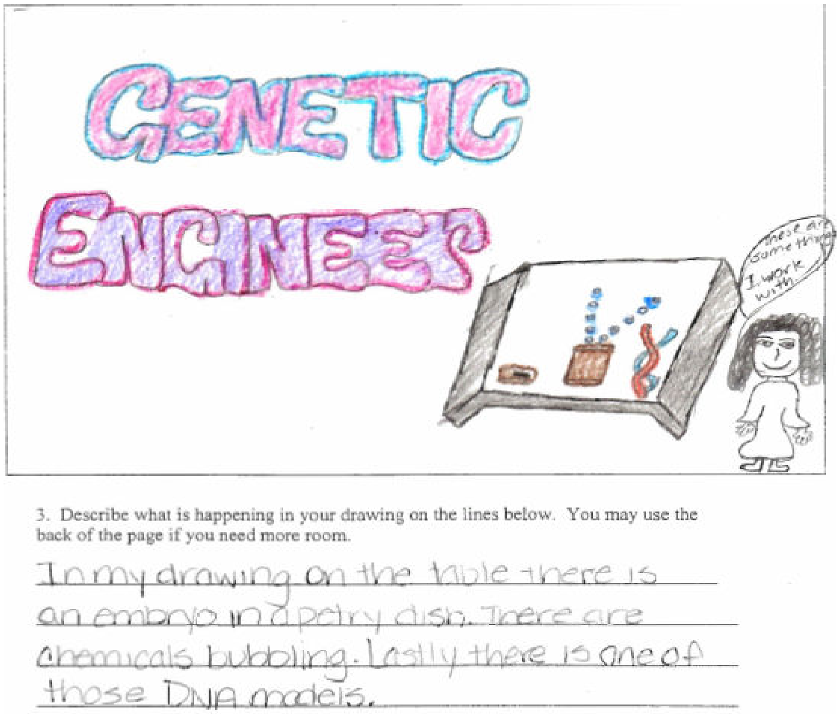
My drawing is a engineer that is a
water specialist. They use test tubes,
heaters, and beakers. Water specialist
test water to make sure it is
healthy to drink and use.

Figure 1. Project Student Work sample. Caption reads, "My drawing is an engineer that is a water specialist. They use test tubes, heaters, and beakers. Water specialist test water to make sure it is healthy to drink and use".

This combination of data indicated that project students better understood the types of tools and equipment used by engineers as well as the role models, symbols, and other mental representations play in engineering.

Fields

Project students also portrayed and described significantly more fields of engineering than did control groups students, t, (164) = 3.189, $p < .05$ (two-tailed). Project students were more likely to portray engineers engaged in tasks associated with a single engineering field, electrical engineers fixing a power line for example. Project students were also more likely to explicitly name a field or fields of engineering, with six different engineering fields referenced or discussed across project student work samples and interview data (Civil, Electrical, Chemical, Genetic, Mechanical and Nuclear). In addition to naming specific engineering fields, project students were more likely to accurately portray artifacts used by engineers in those fields. Figure 2 is a representative example of this.



3. Describe what is happening in your drawing on the lines below. You may use the back of the page if you need more room.

In my drawing on the table there is
an embryo in a petry dish. There are
chemicals bubbling. Lastly there is one of
those DNA models.

Figure 2. Project Student Work Sample. Caption reads, “In my drawing on the table there is an embryo in a petry dish. There are chemicals bubbling. Lastly there is one of those DNA models”.

Project students were also more likely to understand that the term engineering encompasses many fields. As stated by this project student during an interview, “There are different types of them (engineers). Some work in medical fields, like genetic engineers and there’s engineers that fix streetlights. There’re also engineers that design roads. That’s all I know” (Student 11).

Control group work samples on the other hand displayed few fields of engineering that could be clearly identified. These students mainly portrayed engineers working in construction and automotive fields. At the same time control group students explicitly referenced just two engineering fields (Mechanical and Electrical) in work samples and interview statements. Further, only two control group students made references to more than one field of engineering. These between group differences support the position that the Engineering Fellows program enhanced project students' understanding of the diversity of engineering fields.

In addition to these findings, analysis revealed major themes apparent in control group data that weren't apparent in project student data. For example, control group students were more likely to portray engineers engaged in physical aspects of building, constructing and/or fixing than their project student counterparts. This assertion is discussed in greater detail in the following section on engineering processes.

Processes

Initial analysis also revealed a substantial mean difference between groups in terms of their understanding of engineering processes (See Table 2). An independent samples t-test found this difference to be statistically significant, t, (164) = 4.541, $p < .05$ (two-tailed). These finding highlight that project students were more likely to understand the large number of mental processes crucial to engineering work while control group students were more likely to focus on physical processes associated with engineering.

An examination of the verbs students used to describe the work of engineers further supports this interpretation. Table 3 shows the verbs most commonly used by the two groups when discussing the work of engineers.

Table 3. Verbs Used to Describe Engineering Work by Group

Control Group	Frequency (percentage)	Project Group	Frequency (percentage)
Fix	13	Fix	23
Build, Make	9	Test, Experiment	11
Drive, Operate	7	Design, Redesign	9
Tell	2	Research	7
Install, Screw, Hammer, Mix, Take, Find Solution	Less than 1 each	Invent	7
		Build, Make	7
		"See" (determine),	5
		Paint, Tell, "Come up with"	2 each

This table highlights that both groups were most likely to use the verb "fixing" to describe what the engineers were doing. However, the next most frequently used verbs differed substantially between groups. Project students were more likely to use verbs that would be associated with mental work such as “testing”, “researching”, or “inventing”. Conversely, control group students were more likely to use verbs associated with physical work such as “building” or “driving”. When these verbs are examined collectively it appears that control group students perceived engineering processes to be more physical than mental.

This interpretation is further supported by an examination of the verb fixing and the way it was used differently by the two groups. When project students discussed fixing, they mainly focused on mental aspects of fixing. This is seen in this example, “Well these are engineers and they’re finding out what went wrong with this rocket, things that need fixing on the rocket” (Student 11, interview). It is also seen in this example “Engineers help make things better in life, like machines. To figure out how to fix them, make them better” (Student 19, interview). When control group students discussed fixing, the focus was primarily on physical aspects of fixing. This is seen in this example, “I drew an engineer fixing under the car because oil was leaking and he had put in an engine. He needed these tools (wrench, torch) to fix it” (Student 131, work sample). It was also seen in this example “I think they use tools to fix stuff on cars. They fix cars when they are broken” (Student 15 interview). In this way control group students held incomplete perceptions of engineering.

Project student work samples and interview data also emphasized making things better and problem solving as important engineering processes. Figure 3 demonstrates the notions of engineer as problem solver as well as the focus on mental aspects of engineering previously discussed.

3. Describe what is happening in your drawing on the lines below. You may use the back of the page if you need more room.

The Engineers Are Seeing whatmade the rocket fall when it first took off
The women is the apprver and she tells the other engineers how to re design The Palmetto.

Figure 3. Project Student Work Sample. Caption reads, “The engineers are seeing what made the rocket fall when it first took off. The woman is the approver and she tells the other engineers who to redesign the Palmetto”.

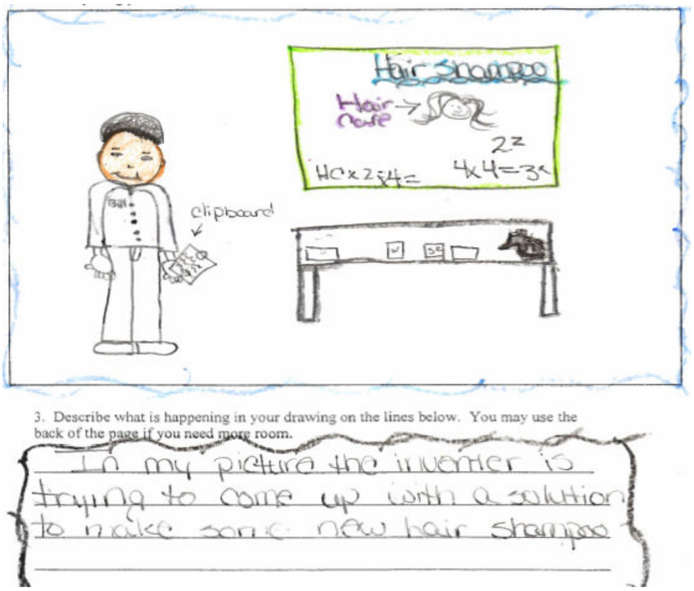
Differences between groups can also be seen in student responses to prompts associated with engineering processes. Project responses focused on mental aspects associated with fixing, “Well these are engineers and they’re finding out what went wrong with this rocket, things that need fixing on the rocket” (Student 11, interview). They focused on making things better, “Engineers help make things better in life, like simple machines. To make things better, less harder” (Student 19, interview). They also focused on making work easier, “They build things and try to make them, I guess, make it easier to everyone else. Make it more, have the ability to work better” (Student 12, interview).

Control group response themes on the other hand focused on construction work, “Construction work. They find out which parts go with which parts” (Student 2, interview). They also focused on automobile repair, “I think they do work on cars, fix stuff on cars” (Student 5, interview).

Portrayals

The Process category previously discussed was designed to give credit to those students who understood that engineering work involves multiple processes, with the core engineering processes being mental. The Portrayal category on the other hand was designed to give credit to students who made distinctions between the various types of mental work completed by engineers. For example, some engineers are technicians. However, technical work does not require the same cognitive and creative demands as the work of design engineers. Students who better displayed an understanding of the connections between these higher cognitive demands and engineering earned higher scores in this category. As with the other Scoring Guide categories, analysis showed a substantial mean difference between groups within this category (See Table 2), with an independent samples t-test revealing statistical significance, $t, (164) = 4.581, p < .05$ (two-tailed).

The Control group mean for this category was .77, indicating that these students were more likely to portray engineers as operators of machinery and/or builders/repairmen. The Project group mean for this same category was 1.52, indicating that these students were more likely to portray engineers as inventors, creators, designers, or problem-solvers. Figure 4 is a project student work sample that focuses on the engineer as inventor, thereby highlighting the importance that creativity plays in engineering.



3. Describe what is happening in your drawing on the lines below. You may use the back of the page if you need more room.

In my picture the inventer is trying to come up with a solution to make some new hair shampoo

Error!

Figure 4, Project Student Work Sample. Caption reads, “In the picture is the inventor trying to come up with a solution to make some new hair shampoo”.

In addition to those differences captured by the Scoring Guide, further analysis identified key distinctions in student portrayals of the engineers themselves. For example, project students were more likely to portray female engineers, with 18% of their drawings depicting female engineers. Similar depictions were found in only 7% of control group work samples. Project students also included greater percentages of minority engineers, with 30% including minority engineer depictions. This is contrasted with control group depictions that included minority engineers in 11% of the work samples.

Sources of Understanding

One of the interview questions asked students to share where they got ideas for their drawings. Students’ responses to this question revealed interesting sources of student perceptions. Half of the project students interviewed attributed their understanding to the Fellow they had worked with previously. This theme is captured here in the response given by a project student, “Because my old engineer, we always talked about it (rockets). He worked with rockets like that and we always talked about rockets and that’s where I got the idea for the drawing” (Student 11, interview). On the other hand, control group students mainly attributed their understanding to two sources; parents and car shows. Parental influence is captured by this control group student’s response to the same question, “My daddy, cause he works on cars so I just thought an engineer” (Student 7, interview). The influence of car shows is demonstrated in this control group student’s response, “I got my idea from a TV show, Pimp my Ride” (Student 5, interview).

Summary

Involvement in the Engineering Fellows program significantly influenced student understanding of engineering. Project students less likely to indicate that they didn’t know what engineers do. Project students also better understood the diversity of fields represented by the term engineering and the work typically done within engineering fields. They also moved away from the perception that an engineer is a builder and towards a more accurate perception that an engineer is a designer or problem-solver. Further, project students developed clearer understandings of the multiple processes associated with engineering while holding fewer misconceptions than their control group counterparts.

Discussion

Students' perceptions matter, they influence attitudes toward, and a willingness to engage in STEM related activities. Ultimately perceptions affect career options, contributing to a significant mismatch between the demographics of the STEM work force and the demographics of the general population in the United States. The results reported in this and similar papers[13, 14] indicates that collaborations of this type positively influenced project students' perceptions of engineering, with the impact lasting for years beyond the period of exposure to a Fellow. This exposure to engineering, and the resulting transformational power these types of collaborations seem to have, should be one part of a larger effort to more closely align the demographics of STEM populations in the United States with that of the general population.

The United States has a long-standing history as a world leader in STEM fields, and there is a clearly documented need to increase minority participation in these disciplines in the United States. At the same time a scientifically educated and aware public is necessary in order to guide the adoption, and debate the societal implications, of new sciences and technologies. The first step towards increasing participation in, and developing a greater understanding of, STEM disciplines is to inform K-12 students about STEM disciplines and reduce inaccurate perceptions related to these fields. Programs like this one demonstrate the potential to be a first step towards addressing both of these critical needs.

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