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Introducing Middle School Students to Engineering Principles and the Engineering Design Process Through an Academic Summer Program*

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Forty-seven 5th, 6th and 7th grade students from traditionally underserved and typically underrepresented populations participated in a two-week residential engineering program, The ExxonMobil Bernard Harris Summer Science Camp at New Jersey Institute of Technology during the summer of 2015. Working in small cooperative groups, students were introduced to the Engineering Design Process, taught how to apply the process in developing and testing a prototype and received instruction in how to keep an engineering logbook. Results of evaluations indicate that, in addition to significant increases in Science, Technology, Engineering and Mathematics content knowledge, students showed significant increases in their attitudes toward science, mathematics and engineering and demonstrated increased knowledge about careers in engineering and an understanding of the engineering design process at the conclusion of the program. A rubric has been developed to evaluate students' understanding and application of the engineering design process. Correlations among students' responses to content knowledge pre/post tests and the rubric have been found. The Draw an Engineer Test was also used as a more qualitative assessment of what students think engineers actually do and to capture cognitive changes in their perceptions of engineers as a result of attending the camp.

Keywords: engineering design process; Next Generation Science Standards; problem-based learning; 21st Century skills

1. Introduction

Although the introduction of the Next Generation Science Standards [1] has helped increase efforts to integrate engineering concepts and principles of engineering design into K-12 science curriculum [2–5], progress has been slow [6]. Many current K-12 teachers are not knowledgeable about engineering or how to integrate engineering principles into their existing curriculum and/or schools have not given them adequate support and the necessary resources [7]. Curriculum materials to support the integration of engineering concepts into science, mathematics and technology classes are also lacking, especially for middle school students. For students, engineering experiences in science and technology class, if there is a separate technology class, are often disjointed and they are not able to see how classroom lessons are related to engineering in the real world. Much of the engineering instruction that students receive is presented in isolation of their mathematics class and not as part of an integrated science, technology, engineering and mathematics (STEM) curriculum [8]. This is unfortunate because students need to realize the value of pursuing a career in engineering and the importance of obtaining the academic background required to study engineering in college as the demand for more qualified engineers in the workforce continues to grow internationally [9].

Summer enrichment programs designed to introduce students to engineering and increase their overall interest in STEM fields can be instrumental in providing young students with essential engineering skills and informing them about careers in engineering [10–12]. The Center for Pre-College Programs (CPCP) at New Jersey Institute of Technology (NJIT) provides a variety of such summer programs [11, 12] starting as early as 4th grade because research has found that many college students in STEM-related majors made their decision to study a STEM-related subject as early as middle school [13, 14].

One of the programs, sponsored by the ExxonMobil Foundation and the Harris Foundation, the ExxonMobil Bernard Harris Summer Science Camp (EMBHSSC) [15], recruits fifth, sixth and seventh grade students from traditionally underserved and typically underrepresented populations, including females, who in addition to not being introduced to engineering in school are less likely to be exposed to engineering outside the classroom or have adults discussing careers in engineering with them. During the two-week camp students stay on the NJIT campus in one of the dorms so that in addition to the academic experiences they get an introduction to what attending college is like.

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1.1 ExxonMobil Bernard Harris Summer Science Camp

The academic curriculum for the EMBHSSC is aligned with the Common Core State Standards and the Next Generation Science Standards and focuses on self-efficacy while providing an interdisciplinary, project-based learning environment that draws mostly on math, science, and technology and fosters essential 21st century skills such as problem-solving, communication, teamwork, independence, imagination and creativity. The curriculum has a space theme, students study the properties of space, analyze and predict how objects move on earth and in space, investigating how people live and survive in space. At the beginning of the program, students are presented with a scenario that contains a core problem to be solved and are assigned to work in heterogeneous groups of four based on grade, gender and their responses to the Multiple Intelligence Test for Young People [16]. Students receive an introduction to the Engineering Design Process (EDP), are taught how to apply the EDP in developing and testing a prototype, receive basic instruction in how to keep an engineering logbook and are required to make a presentation about their solution to the core problem. Presentations must include an outline of how the EDP was applied and a demonstration of their prototype. Incorporating engineering principles, including the Engineering Design Process, into science and mathematics instruction through a problem-solving, inquiry-based pedagogy of this type stimulates students and helps them discover links between their lessons and engineering in the real world. Students need to recognize that scientific inquiry answers questions about the world as it exists while engineering develops solutions to problems people encounter in everyday life [17].

In addition to classroom lessons, students participate in hands-on activities, laboratory experiments, team-building exercises, and go on field trips. Students visit research facilities where they are introduced to engineers and have the opportunity to see first-hand the career options available to them if they should choose to study engineering. Evening exercises include college readiness activities, team-building exercises and a dinner reception with undergraduate and graduate students from a variety of engineering majors at NJIT.

1.2 Engineering and the Next Generation Science Standards

The Next-Generation Science Standards (NGSS) specifies three dimensions for K-12 science education, the first being Scientific and Engineering Practices that includes the following eight steps, all of which are important aspects of scientific inquiry and engineering design:

1. Asking questions (for science) and defining problems (for engineering).
2. Developing and using models.
3. Planning and carrying out investigations.
4. Analyzing and interpreting data.
5. Using mathematics and computational thinking.
6. Constructing explanations and designing solutions.
7. Engaging in arguments from evidence.
8. Obtaining, evaluating, and communicating information.

Unfortunately, these skills are not often emphasized in K-12 science curriculum and when these skills are included they are often presented in isolated lessons that do not necessarily give students an opportunity to experience the full cycle of scientific inquiry or engage in engineering practices that will help students discover the links between their science lessons and engineering. The engineering design process provides an opportunity to teach students about scientific inquiry since the processes are parallel in nature, with similar problem solving characteristics, such that when presented correctly student will make connections between classroom science lessons and the science used in real-world engineering applications [18–22].

Engineering activities should "provide opportunities for students to deepen their understanding of science by applying their developing scientific knowledge to the solution of practical problems" [23]. Multiple opportunities to apply mathematical and scientific principles to solve real-world problems promotes the kind of deep understanding that has been found to form as a result of spaced, repeated learning [24, 25].

The current paper is a summary of the evaluation of the 2015 EMBHSSC. Results of previous evaluations were positive; students demonstrated increased knowledge about careers in engineering and an understanding of the engineering design process [26]. A rubric to evaluate students' understanding and application of the engineering design process was developed and revised for the current study [27]. Expanded instruction and evaluation for the summer of 2015 included; enhanced curriculum, more intense instruction on how to keep an engineering logbook, and examination of elements in students' logbooks using a rubric to evaluating their understanding of the engineering design process.

2. Presentation

Forty-eight students (50% male, 50% female) with equal numbers of post 5th, 6th and 7th graders were selected to participate in the program based on grades, state standardized test scores and letters of recommendation from their mathematics and science teachers. One female student dropped out about half way through the program for personal reasons, leaving 47 students who completed the program.

Students took a content knowledge test, the Middle School Attitudes to Mathematics, Science and Engineering Survey (MATE) [28] and the Draw an Engineer Test (DET) [29] (adapted from the Draw a Scientist Test [30]) before beginning the program and then again at the end of the program. The MATE has been shown to be psychometrically sound and has been used extensively in prior research by the authors [5, 11, 12, 31–33] and others [14, 34, 35]. The DET is a rubric-style checklist that has been developed to quantify the appearance (gender, color, etc.) and location of engineers in students' drawings, as well as to summarize other objects and/or people in the drawing and make inferences of action about what the engineer is doing as a tool to more fully evaluate young students' perceptions of who engineers are and what they actually do.

The content knowledge test served as a post-test of the science and engineering concepts covered in classroom lessons and the hands-on activities. The content knowledge test also included a question specific to the steps of the Engineering Design Process as shown in Fig. 1.

The engineering design question presented students with the design circle shown below with nine numbered, but empty spaces, and asked them to fill in the steps of the Engineering Design Process. The test also contains a question that requires students to define a Prototype.

2.1 Middle school attitudes to mathematics, science and engineering survey

The Middle School Attitude to Mathematics, Science and Engineering Survey measures the

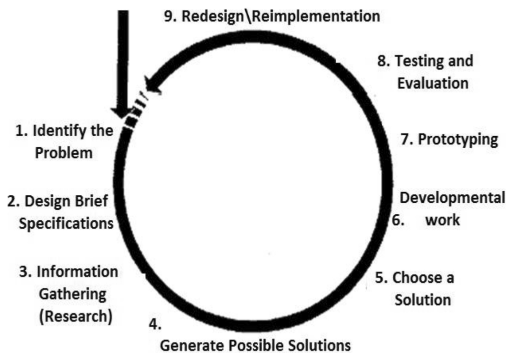

Fig. 1. The Engineering Design Process.

extent to which students agree or disagree with statements related to their beliefs about mathematics, science and engineering, and their self-efficacy for problem-solving and engineering skills using a 6-point Likert scale; the typical 5-point Likert scale with an option that allows students to indicate "I don't know". Students' responses to the MATE are grouped into seven categories (subscales): Interest in engineering—stereotypic aspects (Stereotypic) (e.g. I would a job where I could help design buildings.); Interest in engineering—nonstereotypic aspects (Nonstereotypic) (e.g. I would like a job designing devices to help people walk better.); Negative Opinions and stereotypes of Engineers (Negative) (e.g. Only nerds become engineers.); Positive Opinions of Engineers (Positive) (e.g. Engineers help protect the environment.); Problem Solving (Problems) (I like problems that can be solved in many different ways.); Technical Skills (Technical) (I am good at technical things.); and Gender Equity (Gender) (e.g. Girls are just as good at math and science as boys.).

In addition to students' attitude to mathematics, science and engineering the MATE also measures their knowledge about careers in engineering with a multi-part open-ended question that requires students to "Name five different types of engineers" and to "give an example of the work done by each type of engineer". Each type of engineer is coded "1" for correct or "0" for incorrect. Possible total scores range from zero to five. Each example of the kind of work each type of engineer does is coded "2" for completely correct, "1" for partly correct, and "0" for incorrect. Possible total scores range from zero to ten. Changes in students' responses to the MATE are used as a measure of the impact of the program on their perceptions of engineers and knowledge of careers in engineering.

2.2 Engineering design challenge

The rationale for presenting middle school students with a design challenge developed from the Centers' success in co-sponsoring the Creative Design Challenge (CDC) for high school students with the Panasonic Corporation [36]. Students' oral presentations, written reports and engineering log books from the CDC showed evidence that they understood and could apply the engineering design process to formulate a competitive solution to a problem when presented with a specific challenge. The challenge for the middle school students in the summer program was developed to be more grade and age appropriate than the various challenges given to the high school students each year in the CDC and as indicated above the results were very positive.

To begin the program, students are presented with a real-life scenario which includes a problem to be solved, (i.e. a design challenge). Students attend a mock "NASA Press Conference" during which they receive a copy of the following press release and view a "Breaking News" video that outlines the details of their upcoming mission.

NASA ANOUNCES FAMILIES WITH CHILDREN TO LIVE IN SPACE

NASA has just announced that beginning next year, astronauts will begin living and conducting research for extended periods of time aboard the new International Space Station. A decision has been made for their families to travel and live with them. As a result, entire families including children will be living in space aboard the Space Station. Preparation and training for children will begin this week as part of what NASA is calling the "Engineering Your Place in Space Academy". Children will study the properties of space (earth science) and learn about how people live and survive in space (life science including health and nutrition). They will need to understand the effects of micro-gravity and how things operate differently in space (physical science). Graduation from the Academy will require designing a prototype of a living place for themselves in space (engineering and technology) including a report on their background research and design development. The Space Commander explained that "these children need to start thinking about how living in space will affect their lives and what their living space will look like? How will they do their schoolwork and store their clothes, toys and other belongings in zero gravity?". Designing their own small "Place in Space" will be a challenge for these children and they need to start training immediately.

Students are given the opportunity to ask questions which lead into a presentation about the International Space Station and a discussion about living in microgravity. Students are then assigned to work in heterogeneous teams of four based on grade, gender, and the spatial, logical mathematical, linguistic, intra-personal and inter-personal subscales of Multiple Intelligence Test for Young People [16] because research has shown that working in heterogeneous groups such as these produces the benefits of increased learning that occurs when students collaborate and follow structured protocols [37]. Students participated in multiple hands-on activities designed to introduce them to the Engineering Design Process (EDP) and provide opportunities for them to learn how to apply the EDP in solving problems and developing prototypes under different conditions. In addition to designing their own "Place in Space" each team of students was challenged to identify something they would need (or want) to take into space with them that would not function properly in microgravity and "re-design" it for use in space.

Students learned about the importance of keeping an engineer's logbook and received detailed instruction in how to keep an engineering log book including documentation of original ideas, attention to constraints and cost, detailed sketches, dating their work, signature of witnesses and results of testing their prototype. As a culminating experience, each team of students prepared a science fair type presentation about their living quarters and prototype for program staff, their parents, siblings and other family members as part of a closing ceremony at the end of camp. Presentations included an overview of how they applied the EDP in developing their solution and a demonstration of their "re-designed" prototype.

3. Results

Results of evaluations from previous summers were positive [26, 27]. Changes in the curriculum and evaluation during the summer of 2015 include a modified scenario and core problem, more rigorous instruction for keeping an engineering logbook and inclusion of the logbooks in evaluating students' use of the engineering design process.

3.1 Content knowledge

Students' scores on the content knowledge pre-test ranged from 10 to 70% with an average of 33%. Scores on the post-test increased significantly, ranging from 60 to 100% with an average of 77% ($t = 18.6$, $df = 46$, $p < 0.01$). Although the pre-test scores for the 7th grade students were slightly higher than for the 5th and 6th grade students, no significant differences in improvement were found among the three grade levels or between the male and female students using repeated measures analysis of variance techniques.

3.2 Engineering design process question

At the beginning of the program only 16 students attempted to fill in any of the steps for the question on the engineering design process, and none of them were very accurate. Only four students indicated that the process begins by identifying a problem, and three (one of the four students who began with identifying a problem and two others) indicated one of the steps somewhere was to build a model/ prototype. Despite the fact that these were all bright students, interested in attending a summer science camp with an engineering theme, they showed very little prior knowledge of the engineering design process. This was further evidenced by the fact that very few students (14%) were able to give even a vaguely accurate definition of a prototype.

At the end of the program, 30 students (64%) were able to fill-in all 9 steps of the EDP completely correct. Another six students (13%) made a mistake on only one step by either leaving out a step or by putting a step in the wrong order. Of the remaining

10 students, most made only two errors and none of them left the question blank. Most students (87%) were also able to provide an accurate definition of a prototype.

But providing accurate definitions is declarative knowledge and does not necessarily mean students have acquired adequate procedural knowledge to apply the EDP in problem solving. A rubric (see Table 1), that has been found to be a more comprehensive measure of students' understanding of the engineering design process and their ability to apply the EDP, was developed as part of the evaluations during previous summers. Much discussion went into the development of the rubric and several experts in the area of engineering design were asked to review the rubric, and the 4 point scale for content, before piloting. The psychometric properties of the rubric were reported previously [27].

3.3 Evaluation of the engineering design challenge

The rubric, as shown in Table 1, was used to evaluate students' understanding and application of the engineering design process through students' closing ceremony presentations and examination their engineering logbooks including sketches. Program teachers and other project staff were familiar with the use of the rubric from prior years although only students' group presentations were evaluated. During the current evaluation, in addition to their presentations each groups' engineering logbook was included when completing the rubric.

Using the rubric, evidence for each step of the EDP is scored on a scale from 0 to 3. Total scores are determined by summing the scores across all nine steps on the rubric. Total possible scores range from 0 to 27. Each group was assigned a presentation score by averaging the total rubric scores from three different raters. Scores ranged from 14 to 26. Although not highly significant due to the small sample size, a strong correlation was found between each group's presentation score and the number of people on each team that correctly identified all 9 nine steps of the engineering design process correctly on the post-test ($r = 0.51$, $df = 11$, $p = 0.09$).

3.4 Attitudes toward mathematics, science and engineering

Students' attitudes toward mathematics, science

Table 1. Rubric for Evaluating the Engineering Design Process

Step 1: Identify the Problem	(3) Clearly stated and worded, meets the criteria (2) Adequately stated and worded, meets most of the criteria (1) Poorly stated & worded, does not meet a majority of the criteria (0) Did not include problem statement
Step 2: Framing a Design Brief	(3) Clearly stated, meets all the criteria & specifications (2) Adequately stated, meets most of the criteria & specifications (1) Poorly stated, does not meet the majority of the criteria (0) Did not include the design brief
Step 3: Research & Investigation	(3) Thoroughly did research of various components of their design (2) Did adequate research of various components of their design (1) Did poorly research of various components of their design (0) Did not do/include research
Step 4: Generation of Alternative Solutions	(3) Generated 3 + thorough sketches of possible design solutions (2) Generated 2 adequate sketches of possible design solutions (1) Generated 1 adequate/poor sketch of a possible design solution (0) Did not include sketches of possible design solutions
Step 5: Choosing the Best Solution	(3) Thoroughly explained how they objectively chose their solution (2) Adequately explained how they objectively chose their solution (1) Didn't thoroughly explain solution choice or chose solution objectively (0) Did not include how they chose the best solution
Step 6: Developmental Work	(3) Created thorough sketches, bill of materials, steps needed to create design (2) Created adequate sketches & bill of materials/steps to create their design (1) Poor sketch, didn't include bill of materials or steps used to create design (0) Did not include developmental work
Step 7: Prototyping	(3) Well-designed prototype, allows for testing, Works properly, looks good (2) Created a prototype that can be tested. Works relatively well, looks decent (1) Created almost complete prototype, may be able to test, doesn't work well (0) Did not finish the prototype
Step 8: Testing and Evaluating	(3) Thoroughly explained how to test prototype, testing process makes sense (2) Clearly explained how to test prototype, testing process could be stronger (1) Did not clearly explain how to test prototype, process not clear (0) Did not explain how to test the prototype
Step 9: Redesign	(3) Made valid decisions for change/improvement based on test results (2) Decisions to change were loosely based on test results (1) Decisions to change were not based on test results (0) Did not make needed improvements

Table 2. Changes in Students' Attitudes to Mathematics, Science and Engineering Scale and Subscales

	Before Beginning Program	End of Program	
	Mean (SD)	**Mean (SD)**	**p-value**
Total Scale:	4.1 (0.6)	4.2 (0.5)	>0.05
Subscales: Stereotypic	3.7 (0.8)	3.8 (0.6)	>0.05
Non-stereotypic	3.3 (0.8)	3.9 (0.7)	**<0.05**
Positive	4.2 (0.4)	4.4 (0.6)	>0.05
Negative*	1.9 (0.6)	1.5 (0.7)	**<0.05**
Problems	4.1 (0.7)	4.3 (0.6)	>0.05
Technical	3.8 (0.6)	3.9 (0.8)	>0.05
Gender	4.6 (0.7)	4.8 (0.6)	>0.05

and engineering (MATE) were very positive even before beginning the program (See Table 2). Previous research has shown that students who elect to attend STEM related summer programs have more positive attitudes toward STEM than other middle school students from similar backgrounds [11, 12, 28, 31, 33]. This is particularly true for students who attend programs at CPCP [11, 12], including the EMBHSSC [26, 27], because students must have a B average in school and provide letters of recommendation from their mathematics and science teachers. These students typically have a more positive attitude towards school, better study habits and enjoy science and mathematics but may not know much about engineering. Therefore, changes in their attitudes toward mathematics, science or engineering are often small and not statistically significant while their knowledge about engineers and careers in engineering show significant increases.

Overall students' attitudes toward mathematics, science and engineering did not change significantly as was expected ($p > 0.05$, see Table 2). No significant differences were found between the male and female students but examination of the individual subscales on the MATE did find a significant increase in students' interest in non-stereotypic aspects of engineering ($p < 0.05$, see Table 2) and a significant decrease in students' negative perceptions of engineering. Students were more interested in "designing devices to help people walk better" or "designing clothes to be worn in space". Students were much less likely to agree that "engineers are nerds" and much more likely to disagree that "engineering has nothing to do with real life" which is very positive. The average response to the "engineering has nothing to do with real life" item on the MATE decreased from 1.5 to 1.1 which means that by the end of the program almost all the students strongly disagreed with this. Students probably did not know that the unusual types of jobs that they learned about during camp involved engineering. No significant differences were found between responses from the male and female students or among the three different grade levels.

3.5 Knowledge of careers in engineering

More promising were the significant increases found in students' responses to the knowledge about engineering careers question (See Table 3). Twenty percent of the students were not able to correctly name even one type of engineer before beginning the program, and almost 65% gave answers that were incorrect rather than leave the question blank. Other questions on the MATE asked students how often their parents, teachers and school counselor talked to them about jobs in engineering; 22% indicated their parents had never talked to them about jobs in engineering; 40% indicated their teachers had never talked to them and almost 60% indicated their school counselor had never talked to them about jobs in engineering. At the end of the program all 47 of the students could correctly name at least two different types of engineers, the majority (89%) named three or more types which was a significant increase ($\chi^2_3 = 42.2$, $p < 0.01$) (See Table 3, Part 1). None of the students left the question completely blank as before, and less than 30% of the students gave any answers that were not correct, like scientist or mechanic.

Only about half the students were able to give even one or two partly correct examples of the kind of work that engineers do before beginning the program and very few were able to give even a partly correct example of the kind of work done by each type of engineer if they named three or more types of engineers. Students may have been able to name different types of engineers but did not really appear to know what they do. Most of the students

Table 3. Changes in Response to the Knowledge of Careers in Engineering Question

	Part 1 Name five different types of Engineers Number of correct responses				**Part 2** Give an example of the kind of work each type of engineer does Total number of points				
	0	**1–2**	**3–4**	**5**	**0**	**1–2**	**3–5**	**6–8**	**9–10**
Before Program	20%	49%	30%	1%	43%	36%	15%	6%	0%
End of Program	0%	11%	38%	51%	0%	15%	40%	36%	9%

(83%) either left this part of the question completely blank (9%) or gave at least one answer that was not correct; More than half gave multiple incorrect examples. By the end of the program every student was able to give at least some correct or partly correct examples of the kind of work done by the type of engineer(s) they named which is also a significant increase (χ^2_3 = 47.5, p < 0.01) (See Table 3, Part 2). The majority (91%) were able to give at least one completely correct example and another example that was at least partly correct. Almost 70% were able to give correct or at least partly correct examples of the type of work done by each of the types of engineers they named although some only named four types not five which is great, and 51% were able to give correct or partly correct examples of the work done by 5 different types of engineers.

3.6 Perceptions of engineers from drawings

Students were asked to draw a picture of an engineer at work and to provide a one sentence description of what the engineer in the picture is doing. Pictures are summarized using the DET checklist [36]. The checklist begins with an examination of the engineer to check the species (i.e. Human?), actual presence, gender, skin color, and other attributes, like glasses, lab coats, crazy hair or other clothes, the location of the engineer (inside, outside, in space, underwater) and finally there is a list of inferred actions that can be indicated, like fixing, designing, teaching, experimenting, building, or even NO action can be indicated. The types of other objects in the drawing are also coded, for instance, the presence of other people, animals, symbols that would indicate math or chemistry, airplanes, computers, cars, trains, signs of thinking, etc. The wearing of a hard hat and a face shield has been added to the attributes as it often hides the gender of the engineer.

Of particular interest are the gender attributions of the engineer and changes in the attribution from pre- to post- in addition to changes in inferred action (i.e. what the engineer is actually doing) by considering not just students' pictures but by also considering verbiage in the students' sentence about what the engineer in the picture is doing. Verbiage in the sentences is examined for the use of it, he, she, my, or the in conjunction with the drawing of the engineer. Students often draw a stick figure with no gender or what appears to be a mechanic with only legs protruding out from under a rocket or car. When a stick figure, an androgynous person or a partly hidden person is drawn and described as "it", "my engineer" or "the engineer" in the sentence then the gender of the engineer is coded as unknown. Verbiage in the sentences was also examined for words to help support designing, creating, testing, problem solving as opposed to building, fixing, operating, driving etc.

3.6.1 Gender attributions

Changes in students' gender attributions of the engineers in their drawings are summarized in Table 4 separately for male and female students. None of the 24 male students drew female engineers either at the beginning (pre) or the end of the program (post). Most of the male students drew male engineers, pre and post. About 30% drew engineers of unknown gender at the beginning and then drew male engineers at the end of the program. Another 25% of the male students drew engineers of unknown gender at both the beginning and the end of the program.

Of the 23 female students, only 3 (13%) drew a female engineer at the beginning of the program. These 3 female students and an additional 8 female students drew female students at the end of the program so that approximately 50% of the female students drew female engineers by the end of the program. Twenty-five percent drew engineers of unknown gender and 25% drew male engineers. None of the female students changed the gender of their engineers from female to male which is encouraging.

3.6.2 What engineers do?

Students' drawings were also coded to describe the overall action or meaning of what the engineer was doing by examining the drawing and the verbiage in their sentence. A few students did not write a sentence and the action or meaning of their drawing had to be inferred. Most often the engineers were coded as working with their hands if they appeared to be doing something with their hands or, nothing if the engineer appeared to be just standing there.

For the current investigation, what the engineers in the drawings were doing was coded as; (1) Designing/Creating, (2) Testing/Improving, (3) Problem Solving/Helping, (4) Programing a Computer, all of which would be considered acurate

Table 4. Summary of Changes in Gender Attributions of Engineers from the Draw an Engineer Test

The Engineer's gender in drawing		Students' Gender	
Pre	**– Post**	**Male**	**Female**
Female	– Female	–	3
Male	– Male	10	4
Unknown	– Female	–	8
Unknown	– Male	8	2
Male	– Unknown	–	2
Unknown	– Unknown	6	4
	Total	24	23

Table 5. Summary of What the Engineers in Students' Drawings were Doing by Gender

	Male		Female	
	Pre	**Post**	**Pre**	**Post**
The Engineer was				
Designing or Creating	1	8	1	9
Testing\Improving	1	3	–	6
Problem Solving\Helping	–	1	2	4
Programing Computer	–	3	1	1
Fixing	9	5	7	2
Working with hands	1	3	3	–
Making or Building	9	1	8	1
Nothing	3	–	1	–

descriptions of what an engineer does or (5) Fixing, (6) Working with their hands, (7) Making/building or (8) No Action, which indicate either misconceptions or a lack of knowledge. Table 5 is a summary of how many of the students' drawings were classified into each of the eight categories at the beginning and the end of the program for male and female students seperately.

At the beginning of the program, students' drawings did not indicate much of a difference between the male and female students in terms of their depictions of what engineers do. Changes in action from nothing, fixing, working with hands, making or building to designing, creating, testing, helping, improving or problen solving indicate desirable improvements in students perceptions of what engineers do. Engineers don't simply fix things, they invent new ways of doing things, solve problems and invent or develop ways to make peoples' lives better.

By the end of the program many of the students' drawings showed growth in their perceptions of what engineers do. Their drawings changed from engineers fixing and working with their hands or doing nothing to designing, solving problems and doing things to help people. And although it is not a statistically significant differnce, more of the females students drew pictures of engineers that were helping or improving which is consistent with prior research [9, 38] that indicates female students are more likely to be interested in occupations that help people (see Table 5).

4. Discussion

Although great efforts are being made to include engineering principles in middle school curriculum they are often introduced in isolation of relevant applications rather than as part of an integrated STEM curriculum through which students are able to see connections between their mathematics and science lessons and engineering applications in the real world [8, 39, 40]. In the absence of engineering principles and applications of the engineering design process in most middle school curriculum summer enrichment programs like the ExxonMobil Bernard Harris Summer Science Camp can be extremely effective in introducing students to engineering in the context of an integrated STEM curriculum. Students showed significant increases in engineering content knowledge, knowledge about what engineers do and careers in engineering, in addition to gaining an understanding of the engineering design process. Students demonstrated and increased interest in pursuing a career in the STEM fields, especially engineering and were able to describe the kind of work different types of engineers do.

Results from the current study also indicate that middle school students, even as young as the fifth grade, can learn and apply the Engineering Design Process. Overall, a significant proportion of the students were able to correctly produce the steps of the engineering design process but more importantly students were also able to demonstrate effective use of the EPD in formulating a solution to a real world problem and developing a prototype. Group presentations and logbooks were critiqued to evaluate students understanding and application of the engineering design process in developing their prototype using a rubric developed by camp staff.

Previous research has suggested that purely quantitative measures derived from surveys such as the MATE [28] are not always sufficient to capture cognitive changes in students' perceptions about engineers and that also including a more qualitative assessment is necessary. As part of the current evaluation, students were asked to draw a picture of an engineer at work and provide a short sentence to describe what the engineer in the picture is doing.

Coding and analysis of the drawing produced by the students in the current study in relation to gender attribution of the engineers and what the engineers where actually doing produced some interesting results. Although both male and female students seemed to demonstrate the stereo-type that engineers are male at the beginning of the program, approximately half the female students indicated a change in their perception by drawing female engineers at the end of the program. None of the male students drew female engineers either at the beginning or the end of the program but the fact that so many of the female students drew female engineers is a positive indication that programs such as the ExxonMobil Bernard Harris Summer Science Camp can be extremely effective in helping young women recognize that they can be engineers also.

In addition to positive results related to gender attribution, analysis of students' drawings indicated the program also had a positive effect on students' knowledge of what engineers actually do. Because there were numerous hands-on activities in which students were able to apply the engineering design process and they had multiple opportunities to interact with engineers from various disciplines, the specific things that the engineers in the students' drawing were designing, improving or testing were quite varied. The fact that the drawings characterized an understanding that engineers solve problems, design new ways of doing things and improve peoples' lives is important if the goal is to encourage more students to pursue careers in engineering.

5. Conclusions

Results of the current evaluation showed that students learned the steps of the engineering design process and were able to apply it to solve real-life type problems. Students came away from the camp experience with a much more accurate perception of what engineering is and what engineers actually do. Most of the female students came into the program with the perception that engineers are male as demonstrated by their pre-drawings of engineers at work, but by the end of the program a majority of them drew female engineers leading to the conclusion that elements of the program enabled young girls to see that women can be engineers too.

Students were enthusiastic about their experience(s) during the program and by the end, showed more positive attitudes toward science, mathematics and engineering. Most importantly, students seemed to change their initial impression that "engineering has nothing to do with real life". Prior to participating in the program, they probably did not know that the unusual types of jobs that they learned about during the program involved engineering. Clearly exposing students to the engineering design process through a hand-on, inquire-based approach with a real life scenario during this particular program broadened students perception of engineers and helped students recognize that engineering is related to real life. Integrated curriculum of this type should be introduced in formal school classrooms during the early middle school years, but until this change comes about, integrated STEM programs are an effective alternative whether offered during the summer, after school or on weekends.

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