AC 2009-2335: ELICITING UNDERSERVED MIDDLE-SCHOOL YOUTHS' NOTIONS OF ENGINEERS: DRAW AN ENGINEER

Tirupalavanam Ganesh, Arizona State University

Tirupalavanam Ganesh, Ph.D., has degrees and experience in engineering, computer science, and education. He has brought this experience to bear in previous research that examined the use of technologies in K-12 settings with diverse students. He has worked with the Children's Museum of Houston on the development and implementation of Robotics-based STEM programming for urban youth. He is the Principal Investigator of the National Science Foundation Award# 0737616, Learning through Engineering Design and Practice.

John Thieken, Arizona State University

John Thieken, MEd, is a PhD student in the Mathematics Education concentration in Curriculum and Instruction at Arizona State University. He has a Bachelors Degree in Mechanical Engineering and currently works as a high school mathematics teacher in Arizona.

Monica Elser, Arizona State University

Monica Elser, M.S., M.Ed., is the education manager for ASU's Global Institute of Sustainability (GIOS). She has expertise in ecology and sustainability education, and administering after-school science clubs. She developed and administers the award-winning Ecology Explorers program and Service at Salado project. At GIOS, she directs the sustainability education programs for the National Science Foundation sponsored Decision Center for a Desert City.

Dale Baker, Arizona State University

Dale Baker, Ed.D., is an international expert in equity issues in science education. She was honored in 2006-07 as a fellow of the American Association for the Advancement of Science for this body of work.

Stephen Krause, Arizona State University

Stephen Krause, Ph.D., is professor of Materials Science and Engineering. His research in engineering education has focused on misconceptions and he has expertise in the development of concept inventories to assess student learning.

Chell Roberts, Arizona State University

Chell Roberts, Ph.D., is an expert Engineering educator and Department Chair of Engineering at the Arizona State University Polytechnic Campus. He is the founder and developer of the Engineering Studio at the Polytechnic that is a model for hands-on engineering education at the high school and college levels.

Sharon Kurpius-Robinson, Arizona State University

Sharon Kurpius Robinson, Ph.D., is an expert in counseling youth and adults in educational and career pathways.

James Middleton, Arizona State University

James Middleton, Ph.D., is Professor of Mathematics Education and Director, Center for Research on Education in Science, Mathematics, Engineering, and Technology. He is an expert in middle school mathematics curriculum development and research in student cognition.

Jay Golden, Arizona State University

Jay Golden, Ph.D., is a faculty member in ASU's School of Sustainability and codirector of the

National Center of Excellence on SMART Innovations for Urban Climate and Energy. He works with the Global Institute of Sustainability education team to bring current engineering research on sustainability in the urban environment to this effort.

Eliciting Underserved Middle-School Youths' Notions of Engineers: Draw an Engineer

Abstract

Learning through Engineering Design and Practice is an after-school program designed to engage female and traditionally underserved youth, in technological design and problem solving experiences. This NSF funded project combines after-school inquiry based activities with cognitive apprenticeships, opportunities to practice workplace skills, and experiences with technology to engage and educate junior-high school youth in the fields of engineering. Cohorts of 24 students were selected from two junior-high schools from a large district in the Southwest. Activities were offered for 78 contact hours during the academic year and 48 contact hours during the summer. Students engaged in after-school meetings (twice a week), fieldtrips, parent nights, and internships related to program content. As part of the evaluation portion of the program students were given a "Draw an Engineer" (DAE) assessment to determine individual preconceived conceptions of engineers and engineering. The DAE assessment was administered at the beginning and end of the school year. Analysis of the pre and post student produced drawings indicated the emergence of three main categories: 1) Engineers in Action, 2) Occurrence of Gender, and 3) Engineers' Clothing. Differences in pre and post drawings showed a shift in student conceptions of engineers by both male and female participants. Drawings produced at the start of the program showed a majority, in both genders, conceiving engineers as individuals who build or repair mechanical apparatus. The post-drawing analysis illustrated a shift in this type of thinking. Students shifted their conceptions from engineers who build to the engineers who think. Data also suggested that students are subconsciously learning that engineers are men. Even though the female participants in this program more than double the number of male participants, the majority (71%) of the pre-assessment drawings depicted a male engineer. This number decreased with the post-assessment drawings indicating only 61% of engineers drawn as male. The overall analysis of the data produced from these student-produced drawings suggests that students have learned a great deal about engineering and engineers throughout the first year of the project. Their experiences with the curriculum and with the volunteer engineers have proved to be an effective resource.

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Theoretical Framework

The recent national emphasis on the design, development, and implementation of K-12 engineering education curricula has increased interest in assessing students' knowledge of engineering. Many adults and students in the US have deficient understandings of engineers and what engineers do[1]. In addition, engineering is among the least gender equitable professions with a workforce that is only 11% female[2]. Researchers have argued that the cause for such a discrepancy has psycho-sociocultural roots that create barriers to female and minority participation[3].

Subject-produced drawings offer a simple and unique way for researchers to assess student conceptions. These student-produced drawings offer a window into human sense making that is often beyond description using mere words. In research, the written and the spoken word, along with numbers, have long been valued over other forms of data. Educational phenomena are generally studied using verbal discourse described via textual discourse where language is given center stage over other forms of data. Visual depictions such as photographs, drawings, images available in print media and national archives, etc., are mostly textualized suggesting that images need words while words do not necessarily need images.

Psychologists, scientists, sociologists, anthropologists, and education researchers, among others have used and continue to use subject-produced drawings in their research. In the 1940s, a research study conducted by Kenneth and Mamie Clark, African American psychologists in the United States, asked African American children between the ages of three and seven to color in an outline of a boy and a girl, specifying that each child image the outline to be themselves. Almost all of the students produced drawings that depicted white children. Kenneth Clark's research was explicitly cited by the then US Supreme Court in its landmark decision of Brown vs. the Board of Education of Topeka, Kansas, 1954, that eventually resulted in public school desegregation. Drawings in this study were used as part of a psychological test to understand how African American children thought of themselves[5]. In the 1950s, anthropologist, Margaret Mead, asked American students to draw pictures of scientists[4]. The "Draw a Scientist Test" (DAST) has been widely used to assess students' attitudes about scientists[5,6,7,8,9].

Participants

Active collaboration with a large school district in the Southwest netted 128 applicants from two junior high schools. Forty-eight students were selected from the 128 applicants and formed into two cohorts of 24 students from each school. A purposeful selection strategy was used to identify the initial group of applicants, as well as the final 48 students. Selection began with project coordinators and district administrators identifying students who fit the following criteria: 1) the student had successfully completed the sixth-grade state standards based exam in Mathematics and Language Arts; 2) the student had no major behavioral or criminal incidents on their records was generated. This initial search yielded a combined list of 171 seventh-grade students. The names of these potential students were separated into two lists, by school. Each individual list was forwarded to the corresponding school principal who then circulated the list among teachers for their input. Teachers were asked to make any appropriate modifications, which included adding students they felt were a good fit with the program. Each school principal invited students who were selected to assemble in the school auditorium where project coordinators presented an overview of the project. At the conclusion of the presentation application packets including a letter of invitation addressed to the student; a form seeking information from students as to why they wanted to join this program; a letter to parents informing them about the project; parental permission form; and a child assent form were provided in both English and Spanish. Project coordinators, district administration, and cooperating teachers selected the two cohorts of 24 students based on the responses in each application. Participant demographics are provided in Tables 1 and 2.

Table 1. Participants by Gender

Gender	Number	Percent
Female	32	67%
Male	16	33%
Total	48	100%

Table 2. Participants by Ethnicity

Ethnicity	Number	Percent
African American	5	10%
Asian American	2	4%
European American	12	25%
Hispanic American	25	52%
Indian American	4	8%
Total	48	100%

Project Activities

Project activities were separated into two sections: 1) School year activities and 1) Summer activities. Activities were offered for 78 contact hours during the academic year and 48 contact hours during the summer. During the academic year each cohort met after school for 90 minutes twice a week, in the school media center. The schedule was adapted to comply with field trips, district holidays, testing days, and half-days. The academic year units consisted of: a) Desert Tortoise - study and simulate desert tortoise behaviors using LEGO Mindstorms NXT robotics by building a toy that behaves like a desert tortoise; b) Circuits/Chain Reaction - study ideas of local actions and global reactions by building chain-reactions using Pico Crickets, found objects, and electrical circuit components; and c) Urban Heat Island - study the heat island phenomenon and build models to mitigate heat. Students were also afforded the opportunity to engage in fieldtrips, parent nights, and internships related to program content. Fieldtrips included a visit to the state zoo and visits to solid-state engineering/materials science and sustainability labs at the local research-intensive university. During the summer, students experienced a youth-docent ship at the state Science Center and an industry-internship with a local power and water company.

Cognitive apprenticeships were provided through undergraduate student interns from STEM programs and active volunteers from industry partners and professional engineering societies. These were aimed at providing participants direct access to individuals in various stages of STEM professions to confront stereotypes about professionals in these fields.

Students and parents attended four parent nights designed to give students an opportunity to share their learning. Two more events specifically designed to elaborate on education and career pathways information were offered. The first focused on eliciting students' notions of current career goals that were then juxtaposed against the multi-faceted aspects of engineering graduates (females and underrepresented populations). The second of these focused on different Engineering fields. Students and parents explored *Engineering Go For It!: Make a Difference, Change the World*[10] with an interactive presentation from the facilitators. This activity introduced Engineering as a human endeavor that is designed to meet human needs.

Desert Tortoise Unit

The charge to students was to design a simulation of a desert tortoise using technology (LEGO Mindstorms NXT software and hardware) and its habitat using found objects in an area on the school grounds. Students studied the behaviors of desert tortoises and their habitats. Students had opportunities to engage and explore with both the desert tortoises and the technologies on their own. They were provided with opportunities to: 1) interact with desert tortoises—baby and adult tortoises were brought to the after-school program; 2) go on a field trips to visit a desert tortoise habitat at the local Zoo where the desert is featured; 3) meet and interact with experts, seek answers, and share ideas—a desert tortoise conservationist visited the after-school program with desert tortoises, and on the field trip to the local Zoo interact with herpetologist and botanist; and 4) explore the topic on their own with print materials (university research magazine focused on desert tortoise), the local Zoo's newsletter feature on the desert tortoise, children's books and poetry on the desert and desert animals (*The Desert is Theirs*[11] and *Desert Voices*[12]), other resources from the state's Game and Fish Department, school and university libraries; and internet resources. Students initially explored the LEGO Mindstorms NXT kits sans the instruction manual so they could creatively explore the tools on their own before reviewing the instructions. Then students were introduced to the engineering design process, following which they engaged in building the desert tortoise toy. Student learning was assessed using pre and post assessments; brief write-ups and sketches describing their design; white board presentations to peers, parents, and adult facilitators on what they have learned; and demonstrations of their simulations.

Circuits / Chain Reaction / PICO Cricket Kit Unit

Students were engaged with the idea of designing a chain reaction of their own after watching the "Cog" a 2003, Honda commercial. The "Cog" sequence begins with a transmission bearing rolling into a synchro-hub. This triggers a series of movements: windscreen wipers 'walk' across the floor, valves roll down a bonnet and carefully weighted tires roll uphill. The commercial ends when the power door locks on a complete Honda Accord are activated, causing the hatchback to close, tipping the car off a balanced trailer and into a final pose in front of the camera. Then, Garrison Keillor inquires, "Isn't it nice... when things just... work?", while the song "Rapper's Delight" by The Sugarhill Gang plays in the background. After watching this two-minute sequence (some watched it more than once), students engaged in a free discussion on what they had watched and expressed that it was a "chain reaction". Notions of chain reactions such as local actions having global impact were discussed. While students were engaged in creating their chain reaction components, other chain reaction videos were constantly looped and displayed on the screen. Students were provided with a variety of technology tools beginning with components for creating a simple circuit (switches, electrical cables, an LED, buzzers, and a battery pack) to found objects (cardboard, coat hangers, aluminum foil, milk/juice cartons, etc). Students created circuits on their own using the provided materials and then progressed to making their own homemade switches using found objects. PICO Cricket kits were introduced and students used the PICO software to program and design intelligent reactions to actions triggered by mechanical actions. Ultimately the entire group in teams of two engaged in a chain reaction. Student learning was assessed using pre and post assessments; brief write-ups and sketches describing their circuit designs; white board presentations to peers, parents, and adult facilitators on what they have learned; and demonstrations of their chain reaction creation.

Urban Heat Island Unit

Students were engaged with the notion of the urban heat island phenomenon in the area where they live by going on a field trip to the local research-intensive university's green building and exploration of various areas on the university's campus on one of two trails to find the best place for having lunch outdoors. Students measured humidity, temperature, and wind at designated locations on the trail and recorded data. Average measures were computed for the group to determine the "best" location with a discussion on which location would be the best. In addition students interacted with graduate student experts who are studying the urban heat island phenomenon at the university's Sustainability department in the "green building". They engaged in a discussion on how the building is designed and what materials were used in its construction that contributes to keeping the building "cool" and maintaining low energy use. Students along with the graduate student experts engaged in measuring the temperature of different types of surfaces (grass, concrete, foam, metal, etc) and a solar energy panel experiment to generate energy. Students explored print materials (e.g., the university's research magazine issue on Urban Ecology). Subsequently, students engaged in experiments on their own school campus to measure the temperature above the surface and at 4 feet on various surfaces (grass, soil, concrete, parking lot surface) in shaded and un-shaded areas. They used indoor/outdoor thermometers and infrared thermometers. They designed a "room" using paper cups and cardboard boxes that could maintain the temperature of materials (e.g., water) in the room by using different insulation materials (e.g., fiberfill, bubble wrap, gravel, Styrofoam). Student learning was assessed using a pre assessment, brief write-ups in student journals, and demonstrations of their designs.

Education & Career Pathways Activities

Students and parents were offered two education/career pathways workshops. The first of these focused on eliciting students' notions of current career goals that were then juxtaposed against the multi-faceted aspects of engineering student graduates (females and underrepresented populations). The second of these were facilitated by project directors and were featured on the different Engineering fields. Students and parents explored *Engineering Go For It!: Make a Difference, Change the World*[10] with an interactive presentation from the facilitators. The experience started with a review of images from the "Engineering Is…" sections (pp. 4-9) of the publication that was followed by small group discussions with participants and family members. Participants focused on one of their chosen topics from the publication and engaged in a discussion with their family members. Project coordinators facilitated a discussion about what is engineering and how engineering impacts our daily lives. Undergraduate engineering students studying electrical, mechanical, chemical, and aeronautical engineering made short presentations on their area of study and how their field of study impacts human lives. These students acted as ambassadors of their fields and described how engineering and the sciences are relevant to their own interests and why they are pursuing their chosen education pathways. Participants and family members had the opportunity to ask questions and interact with the undergraduate engineering students. Participants took a copy of the magazine home with them to keep and explore at their leisure.

State Science Center Youth Docentship

Participant youth had opportunities to explore the center's interactive exhibits that are linked by themes to explore different aspects of science. Experiences included the following: Hands-on exploration of energy creation by designing wind turbines, review of wind versus water uses for energy purposes; an exploration of the looming scarcity of fresh water supply and its uses via the IMAX movie "the Grand Canyon Adventure: River at Risk"—an exploration of global water issues; and shared an activity with the general public in the center's Fabrication Lab regarding energy generation using a wind powered generator. Participants and family members had the opportunity on the final day of the youth docentship experience to explore the center on their own.

Power/Water Company Powering our Future Renewable Energy Summer Internship

This twenty-hour internship provided participants with the opportunity to interact with scientists and engineers who work at the local power and water company. In addition, engaged with hands-on explorations into natural resources, energy conservation, and renewable energy technologies. Participants visited the power/water company facilities, interacted with professionals, explored careers in the energy conservation industries, and built working models to harness energy from the power of the sun and water. (e.g.: Participants built solar energy modules in the form of solar ovens to cook food and tested their designs; and built arrays of photovoltaic cells to power a light bulb.) On the last day of the program, parents attended a showcase presentation of students' work.

Non-Digital Tools for Demonstration of Student Learning

The following tools were used for the facilitation and demonstration of student learning throughout the school year.
Word Wall: An interactive word wall that is accessible for students to add new words that they have learned was used at both school sites. This tool helped enhance students' understanding of how words work as new vocabulary related to the STEM fields explored were visible not only for program participants but also for other users and visitors of the media center (library and computer lab) where program activities were held.
White Boards: White boards and dry erase markers were provided to each team of two students so they could put down their ideas, sketches, and what they have learned to share with peers and adults (parents, teachers, and other visitors).

Engineering Notebooks: Students were provided with a notebook to make their journal entries, add sketches or designs, and organize project materials such as resource handouts, information organizers, etc.

Incentives

In addition to certificates of participation, students were given the choice of receiving a LEGO Mindstorms NXT kit or a PICO Cricket Kit to keep and take home. These were the technological tools that were used during the academic year program. This was used as an incentive for year-long participation in the program.

Methods

This study collected data using a pre-test/post-test followed up by unstructured informal interviews. The pre-test/post-test assessment used for this study was a modification of the *Draw a Scientist* test into the *Draw an Engineer* test (DAE). Students participating in the study were given the DAE test at the beginning of the study and then again at the end of the school year. It is important to note that students in the study were given the pre-DAE test during regular project times and the post-DAE test during school as part of a school wide administration of the DAE test. The purpose of the DAE test was to determine individual conceptions of engineers and engineering. Students were given 20-30 minutes to draw an engineer and answer three questions related to what they had drawn. Test directions and question prompts are given below.

> Close your eyes and imagine an engineer at work … Open your eyes. On the attached sheet of paper, draw what you imagined. Once you have completed your drawing, please respond to the following prompts:
>
> 1. Describe what the engineer is doing in the picture. Write at least two sentences.
> 2. List at least three words/phrases that come to mind when you think of this engineer.
> 3. What kinds of things do you think this engineer does on a typical day? List at least three things.

Project coordinators were careful not to talk about engineers or engineering during the initial presentation given to all students, during the first day of the project, or during the administration of the DAE test. During the DAE administration, project coordinators offered help to clarify directions and question prompts, but they did not offer any ideas or assistance that would influence the students' original conceptions of engineers or engineering.

The informal interviews consisted of one-on-one discussions between project coordinators and students to investigate reasoning's behind their drawings and responses.

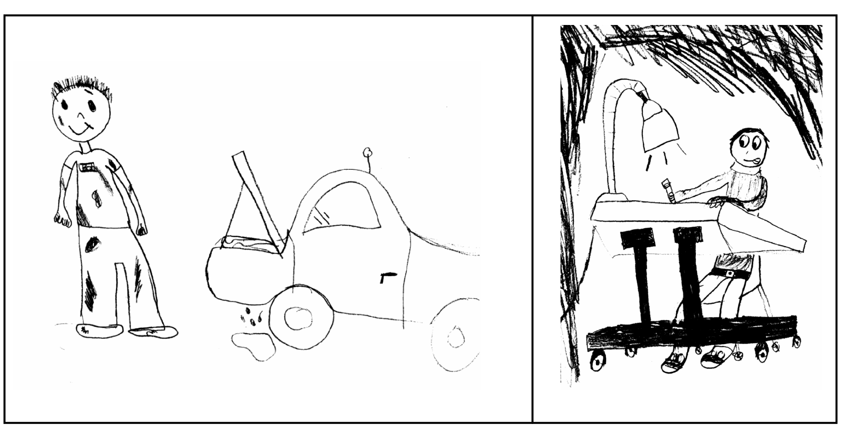
Data Analysis

Due to logistic constraints pre- and post-test data was only gathered for one of the two schools. An open coding approach[13] was used to code the assessments. To begin the coding process drawings and question responses were examined for key elements describing engineers and engineering. In this section we will use the term *drawing* to represent a student's drawing and question responses. Once the researchers felt that all key elements had been identified in the drawing they recorded a short memo describing possible concepts and general thoughts about the drawing. The process was repeated with all 21 pre-test drawings. Upon completion of the initial analysis, researchers organized and reviewed memos and key elements. The set of 21 drawings were reviewed again using the complete list of key elements found during the first analysis. This process was continued until the researchers were satisfied that all key elements had been identified. The same process was used to analyze the post-DAE test. Drawings from the post-test were reviewed using the list of key elements generated by the pre-test analysis. Again, memos and key elements were organized and reviewed. The final stage of the data analysis required researchers to review the entire set of pre- and post-test drawings using the complete list of key elements generated from the initial analyzes. Review of the key elements and memos reveled three main descriptive categories: 1) Actions, 2) Gender, and 3) Clothing.

Evidence and Data Sources

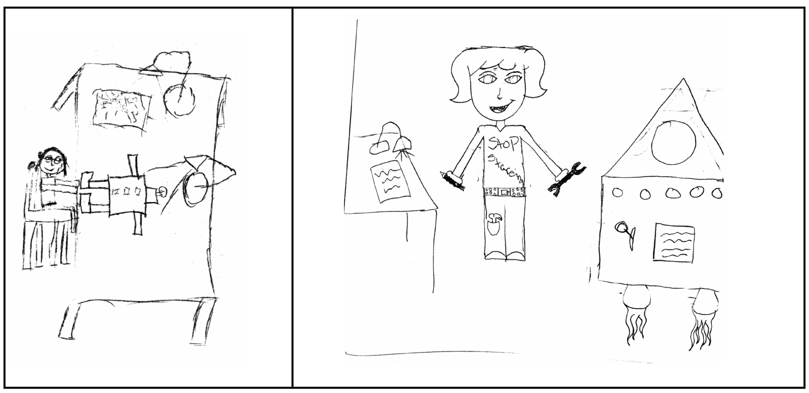
Engineers in *Action* encompassed the greatest and most diverse set of key elements. Key elements that depicted an engineer in *Action* included drawings of engineers building, repairing, designing, studying, and experimenting. For the purposes of this analysis, building and repairing were combined into one component and designing, studying, and experimenting were combined into a second component. Drawing recorded as *Repairing/Building* portrayed engineers working on an object, bent over an object, or seated holding an object with both hands. In this description an *object* refers to any item that does not represent a book, a writing utensil, or material(s) to write on. Drawings recorded as *Designing/Studying/Experimenting* portrayed engineers writing, reading, surrounded by components/gadgets, or surrounded by glassware. Were the indicators of writing and reading included holding writing utensils, holding materials to write on, papers with writing, or books in plain sight. Drawings that showed engineers *Repairing/Building* and *Designing/Studying/Experimenting* were accounted for in both components. Figure 1 shows and examples of student drawings where the engineer's actions can be categorized by a single action, repairing and designing.

Figure 1: Student examples of an engineer repairing and an engineer designing.



The left drawing in figure 1 shows an engineer working on a car. Researchers felt the open hood, the dripping liquid, and the dirty close depicted a person repairing a car. However, an argument could be made that the student is depicting an engineer experimenting on the car's engine. This drawing is a good example of why the data analysis considered both the drawing and the question responses to identify key elements. This analysis was confirmed by the student's description of the picture as, "The engineer is fixing a car. He is trying to fix it and solve the problem". In the right drawing we can see the engineer seated at a desk writing. This type of drawing was categorized as designing. This analysis was confirmed by the student's description of the picture as, "He is designing a project on a drawing table." Figure 2 shows and examples of student drawings where the engineer's actions include two action categories.

Figure 2: Student examples of an engineer building and designing.



In the drawing on the left of figure 2 we can see the engineer seated at a desk building a robot and we can see a reference sheet of some kind to her left. Since the drawing includes an engineer working on an object and a reference sheet it was categorized as both designing and building. This analysis was confirmed by the student's description of what the engineer is doing in the picture, "My engineer is using her blue prints to build a robot." The drawing on the right shows an engineer standing with a pen in one hand, a wrench in the other hand, a rocket, and a reference sheet on the table. This drawing was categorized as both designing and building due to the drawing and the student's description of the picture as, "My engineer is fixing a rocket. Plus, she is thinking of what to build by planning it on a piece of paper." The percentage breakdown according to pre- and post-test as a function of all students and male/female students is shown in Table 3.

Table 3. *Images in Students' Drawing of Engineers in Action*

Participants	All		Male		Female	
Engineer Action	Pre (n = 21)	Post (n = 18)	Pre (n = 6)	Post (n = 5)	Pre (n = 15)	Post (n = 13)
Building/Repairing	86%	33%	83%	20%	87%	46%
Designing/Studying/ Experimenting	38%	52%	50%	80%	33%	62%

These data allude to a shift in the conception of engineers by both the male and female participants. Before the students had experienced the curriculum designed for this project the majority in both genders conceived engineers as individuals who build or repaired mechanical apparatus. Upon completion of the first year there exists a shift from the engineer who builds to the engineer who thinks. Both genders show an increase in the number of student who drew engineers in less labor-intensive activities.

Gender occurrence is a relatively straightforward element. Table 4 illustrates that somewhere in their experiences students are subconsciously learning that engineers are men. Even though the female participants more than double the number of male students, the majority (71%) of the pre-DAE tests depicted a male engineer. As the post-DAE test data indicates, the number of engineers drawn as female increased by 16%. One female stated in the pre-DAE test that an engineer could be male or female, "I see him/her programming the robot." Interestingly, enough there were male students, one in the pre- and one in the post-test, who depicted their engineers as female.

Table 4. *Occurrences of Gender*

Participants	All		Male		Female	
Drawing Gender	Pre (n = 21)	Post (n = 18)	Pre (n = 6)	Post (n = 5)	Pre (n = 15)	Post (n = 13)
Male	71%	61%	83%	80%	67%	54%
Female	23%	39%	17%	20%	27%	46%

Engineers' Clothing included drawings that showed engineers in business, work, or other dress. For a drawing to be coded as business the engineer was illustrated in a suit, tie, or button up shirt/blouse. Engineers wearing coverall, lab coats, or shirts with pockets holding pens were coded as work dress. Any illustration that didn't fit into business or work was coded as other. The percentage breakdown for this category is shown below in Table 5.

Table 5. *Images in Students' Drawing of Engineers' Clothing*

Participants	All		Male		Female	
Engineers' Clothing	Pre (n = 21)	Post (n = 18)	Pre (n = 6)	Post (n = 5)	Pre (n = 15)	Post (n = 13)
Professional	14%	11%	33%	20%	7%	8%
Working	19%	39%	0%	20%	13%	46%
Other	48%	28%	50%	40%	47%	23%

With 48% of the pre-assessment drawings falling under the heading of other, this suggests a lack of understanding for what an engineer might wear when performing their professional duties. Since the type of dress is influenced by the profession, a confusion of what an engineer might wear implies a confusion of what an engineer does. Students' later confided in the researchers that this aspect of the drawing confused them and they decided to draw their engineer in clothes that were familiar to them, i.e. jeans, t-shirts, tennis shoes, and hats. As the students' learn about engineering and talk to engineers throughout the project they began to formulate a more precise conception of what engineers do and thus the types of clothing that would be appropriate for engineers to wear. This type of transition is evident in the 20% decrease in "other" and the 20% increase in "working" as presented in the post-assessment data.

Conclusions

It is clear from these student-produced drawings that students have learned a great deal about engineering and engineers throughout the first year of the project. Their experiences with the curriculum and with the volunteer engineers have proved to be an effective resource. It is important to note that volunteer engineers and undergraduate student mentors included females (40%) and males (60%). Further research needs to be conducted to determine why female students are still drawing male engineers. Investigations into this notion will need to begin with semi-structured interviews with project participants and focus group meetings.

A large number of participants depicted engineers as people who fix things. Further analysis of participants' responses indicate that students described repair-type activities, such as repairing cars, car engines (auto mechanics) and plumbing—traditionally blue collar and male-dominated fields. Many students said that they have at least one family member, usually a male who works on cars in their home. The middle school grades are crucial for students' planning course work in high school and developing potential career pathways. In this context, perception of engineers as auto mechanics—as persons who fix cars—can be (and is) discouraging to many, especially females, from considering engineering as a possible career.

We found that the preconceptions of engineers as "engineers work on engines" did change by the end of the year-long project. Students' concepts about engineers expanded to include multiple engineering disciplines such as chemical, civil, and electronics engineering and depictions of a larger percentage of females (39%) as engineers. This change in perceptions of engineers can be attributed to project efforts that provided multiple opportunities for students to engage with volunteer engineers and undergraduate engineering students in both formal and informal settings. In addition, the use of the engineering design process in project activities and the project activities themselves engaged students with the idea of engineering in a very broad sense.

Educational Importance

The assessments used in this project should serve as testimony to the educational community. Formal assessments do not have to be teacher-structured questionnaires that serve only to limit student responses. In this type of assessment format, where the student is allowed to visualize his/her response and then draw their imagination, the potential for eliciting higher order thinking is limitless. This is not to imply that this type of assessment technique is without its drawbacks. Limitations in this type of assessment do exist and they are directly related to participants' skill level in drawing. Care should be taken to design assessments that allow for a broad range of skills in making drawings.

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