AC 2010-514: TRACKING MIDDLE SCHOOL PERCEPTIONS OF ENGINEERING DURING AN INQUIRY BASED ENGINEERING SCIENCE AND DESIGN CURRICULUM

Jade Mitchell-Blackwood, Drexel University

Jade Mitchell-Blackwood is a Ph.D. candidate in the Department of Civil, Architectural and Environmental Engineering at Drexel University. She will complete her Ph.D. in 2010. Jade is a 2nd year NSF GK-12 Fellow. She has also received support from the U.S. Dept. of Education GAANN Fellowship Program and the National GEM Consortium. Her research focus is in the area of quantitative microbial risk assessment, specifically using analytical models to inform risk based decisions about pathogens in the environment. She has been the recipient of a Student Merit Award from the Society of Risk Analysis' Biological Stressors Specialty Group for the past 3 years. Her research has also been recognized with a Drexel University Graduate Research Award. She has several years of professional experience in Civil Engineering and holds a B.S. from the University of Pittsburgh and an M.S. from Drexel University.

Manuel Figueroa, Drexel University

Manuel Figueroa is a Ph.D. candidate in the School of Biomedical Engineering, Science and Health Systems at Drexel University with a research focus on the fabrication of surface-enhanced Raman scattering (SERS) substrates for the detection of biological molecules. His interests include helping to increase the number of underrepresented minorities in the STEM fields as well as exposing students to nanotechnology for medical applications. He holds a Bachelor's degree in Biomedical Engineering from Tulane University. Manuel is a 2008-2010 NSF GK-12 Fellow and was previously a LSAMP Bridge to the Doctorate Fellow. He is also a current member of the AAAS, ASEE, and SPIE.

Chatchai Kokar, Drexel University

Chatchai Kokar received his B.A. degree in Biological Science in 2009 from Drexel University. Upon graduating, Chatchai spent a year working as a lab assistant in the Biomedical Engineering Department, where he conducted research on the optical properties of nanoparticles for fabricating surface enhanced Raman scattering substrates. Starting August 2010, Chatchai will be attending St. George's University School of Medicine where he plans to earn his M.D.

Adam Fontecchio, Drexel University

Dr. Adam Fontecchio is an Associate Professor and Assistant Department Head in the Drexel University Electrical and Computer Engineering Department, and an Associate Dean of the College of Engineering, Co-Director of the A. J. Drexel Nanotechnology Institute, an affiliated member of the Materials Engineering Department, a member of the Center for Educational Research, and his research focuses on the area of nanophotonics. He is the recipient of a NASA New Investigator Award, the Drexel Graduate Student Association Outstanding Mentor Award, the Drexel University ECE Outstanding Research Achievement Award and the International Liquid Crystal Society Multimedia Prize. In 2003, he received a NASA/ASEE Summer Faculty Fellowship to research NEMS/MEMS adaptive optics in the Microdevices Laboratory at the Jet Propulsion Laboratory.

Eli Fromm, Drexel University

Dr. Eli Fromm is the Roy A. Brothers University Professor and Director of the Center for Educational Research in the College of Engineering of Drexel University. He has held a number of academic leadership positions and included among them are Vice President for Educational Research, Vice Provost for Research and Graduate Studies, and interim Dean of Engineering at Drexel. He has also held positions with the General Electric and DuPont companies, has been a staff member of the Science Committee of the U.S. House of Representatives as a Congressional

Fellow, a Program Director at NSF, and a Visiting Scientist with the Legislative Office of Research Liaison of the Pennsylvania House of Representatives. He has been Principal Investigator of a number of bioengineering research projects involving implantable transmitters and sensors and their use in physiologic measurements. He was the Principal Investigator of the Drexel E4 educational reform project, the Gateway Engineering Education Coalition and is currently PI of an NSF funded GK-12 project. He is member of the NAE and a fellow of the ASEE, the IEEE, and the AIMBE. He is the recipient of a number of other awards and honors including the Bernard M. Gordon Prize of the National Academy of Engineering.

Tracking Middle School Perceptions of Engineering during an Inquiry Based Engineering Science and Design Curriculum

Abstract

As the United States tries to remain technologically competitive with other nations the demand for engineering professionals is expected to increase. Since the early 1990's, many K-12 engineering outreach programs have been incorporated into middle schools either through high tech electives or in tandem with the State prescribed math and science curriculum with the intent of fostering student interest in science and engineering. In spite of both approaches the ratio of science and engineering degrees awarded annually to the college aged population in the U.S. is less than in other countries. Furthermore, the number of underrepresented minorities earning those degrees is 12% according to the National Action Council for Minorities in Engineering, Inc.

Some K-12 programs focus on mutual concepts that appear in both engineering and the physical sciences (engineering science) rather than design and problem solving (engineering design). It is no coincidence then that middle school students do not know what engineers are or what they do in practice. Hence, they do not choose engineering as a possible career choice. While the former has its merits with regard to enriching math and science education for students, the later is necessary for a true understanding of engineering as a profession. Here we examine changes in students' attitudes toward math and science, as well as their development of ideas about engineering after receiving instruction using both approaches - a science curriculum with integrated engineering concepts and applications; and through an engineering design and technology curriculum. Similar trends were observed in both groups.

Specifically, we examine the responses from a 5th grade science class and both 6th and 8th grade robotics classes, who participated in the National Science Foundation (NSF) sponsored GK-12 Program with Drexel University in Philadelphia, PA. In each class, a doctoral candidate in an engineering discipline developed and delivered lessons and activities along with the teacher. Fellows were responsible for designing inquiry-based lessons to enhance the understanding of science, technology, engineering, and mathematics (STEM) concepts with the purpose of inspiring students to eventually pursue engineering disciplines. In the 5th grade class lessons and experiments were geared toward strengthening the understanding of the science curriculum, using engineering as a contextual vehicle for greater understanding. In the 6th and 8th grade class activities were based on engineering design with a focus on the physical sciences.

Both classes completed two surveys at the beginning and at the end of the 2008-2009 school year – an open-ended survey about engineering and a closed-ended survey about attitudes toward math and science. Survey responses at the beginning of the school year revealed that overwhelmingly students defined an engineer as 'a person who fixes things.' They could not identify specific tasks or problems solved by engineers or any of the technological tools that engineers use. Students did not personally know an engineer and could not identify more than one type of engineer. We present how the attitudes toward math, science and engineering changed over the course of the year between the two classes. We also discuss ways to design a better engineering curriculum at the middle school level based on our experiences.

Introduction

The engineering enterprise is considered to be a pillar of U.S homeland security, economic vitality, and innovation. The links between engineering and technology fields and the health of the U.S. economy have been well established and documented. Engineering contributions are made in major sectors of the economy and can potentially enhance economic performance in others. Therefore, in order to ensure U.S. engineering capabilities, a competent and technologically literate workforce is imperative.[1] In the wake of the 2001 attacks on the U.S., establishing and maintaining a strong domestic technical workforce has also become a pressing matter of national security. The demand for engineering professionals is expected to increase. Concurrently, engineering has been identified as being more susceptible to globalization than other professions. In 2003, 46% of master's degrees and 57% of doctoral degrees were awarded to foreign nationals.[1] The ratio of science and engineering degrees awarded annually to the college aged population in the U.S. is currently less than in other countries. The importance of leveraging all of the domestic talent available highlights another well established problem – lack of diversity in engineering education and the engineering workforce. The number of underrepresented minorities earning engineering degrees is 12% according to the National Action Council for Minorities in Engineering, Inc (NACME). This has been termed as "a quiet crisis building in the United States — a crisis that could jeopardize the nation's pre-eminence and well-being.[2]"

Barriers to increased interest and participation can be categorized into two areas: (1) attitudes and perceptions; and (2) knowledge and performance. One strategy for improving technological literacy and stimulating interest in pursuing engineering careers is the implementation of K-12 engineering programs. Through various forms, these programs have served millions of K-12 students over the past 15 years. Yet a majority of U.S. children have not received significant exposure to engineering.[3] Increased exposure through these programs may lead to an increase in both the quantity and diversity of students pursuing engineering. However, a consensus on the best way to expose children to engineering skills and concepts has not been formed nor has the determination of what is considered developmentally appropriate been agreed upon. Both are still largely under investigation.[4] Several approaches exist for introducing K-12 students to engineering. They include development of classroom materials, outreach activities, engineering contests, sponsored teaching fellows and professional development for K-12 teachers. While each program has its own unique features there are some common threads shared among them - active learning through hands-on activities, inquiry-based learning, curriculum supplements, engaged role models, middle and younger student focus and K-12 teacher involvement.[5] The most direct approaches involve incorporating classroom materials into the math and science curriculum or as high tech electives. Some K-12 programs focus on mutual concepts that appear in both engineering and the physical sciences (engineering science) rather than design and problem solving (engineering design). Both types of classroom experiences have their virtues. Incorporating engineering into the math and science curricula has the ability of reaching all students, not just those in pre-engineering or technology programs, while offering high tech electives provides enriching design experiences for students and possibly a clearer picture of what engineers do. Often the former process has been geared toward elementary and middle school students, while the later has been designed for high school students. In light of a body evidence supporting that people filter information through the mental structures and ideas created earlier in life, both types of programs have more recently been provided to middle school students. There is still some debate about whether pre-college initiatives in general should focus on math and science and generating interest in engineering or on developing engineering skills.[4]

Overall, these initiatives have the ability to shape students perceptions about engineering, to improve student attitudes and knowledge of engineering and clarify possible misconceptions.[2] They also introduce students to potential role models. With regard to student interest in engineering careers the perception of engineering and engineers is as important as having role models. [4] Both are particularly vital in the underrepresented minority population and these programs offer an exposure component that is likely to be absent elsewhere in the students' lives. While numerous factors contribute to the diversity issue in STEM fields, the lack of minority STEM professionals and role models has a direct and cyclic affect on minority students' conceptions, misconceptions, understanding and respect for the engineering profession. Chubin et al 2005[6] states that, "it is a matter not only of what is taught, but moreover who is taught, and before that, who is academically prepared, mentored, and socialized to engineering as a career." So, it is no coincidence that despite the efforts of K-12 outreach programs, and particularly for minority students, the concept of what engineers are or what they do in practice is deficient. Hence, the number of students from these demographics choosing engineering as a possible career choice does not represent a cross-section of our population in terms of minorities and/or females.

Previous research makes a strong case that students conceptions and misconceptions about science and engineering have significant and direct implications for curriculum development and learning.[7-12] In order to assess the impact of K-12 engineering initiatives, the students' perceptions, conceptions and misconceptions must be evaluated, as this may be seen as an initial barrier to successfully meeting the goals of such programs. Thus, we have chosen to investigate the conceptions and misconceptions of a minority population of middle school students participating in the NSF sponsored GK-12 Program. The program sponsors a doctoral candidate in an engineering discipline, who develops and implements lessons and activities along with the teacher. Teaching fellows are tasked with designing inquiry-based lessons to enhance the understanding of science, technology, engineering, and mathematics (STEM) concepts in both classes focusing on engineering science as part of the curriculum or classes teaching engineering design with a focus on the physical sciences. The goal of the program is to use engineering as a contextual vehicle for greater understanding of math and science. The broader impacts of the program include creating an interest in STEM, as well as promoting and developing an awareness of engineering as a possible career choice.

Methods

Two surveys were issued to the students at the beginning and end of the academic year 2008-2009 in order to examine changes in perceptions about engineering based on three impact categories: (1) awareness, knowledge or understanding; (2) engagement or interest; and (3) attitude. These impact categories are theoretically grounded in the informal science education professional literature and more broadly in educational research.[13]

An open-ended or short answer survey was used primarily to assess student's knowledge about engineering. This survey emphasized what the student consciously knew and could report in their own words. The following questions were included in our analysis:

1. What is an engineer?
2. What does an engineer do?
3. How does a person become an engineer?
4. Name three types of engineers.
5. What tools does an engineer use?
6. Do you know any engineers? What does that person do?
7. Could you become an engineer one day? Why or why not?

Two additional questions were included in the survey, but for the reasons explained below, excluded from our analysis.
8. Draw a picture of an engineer.
9. What would you like to be when you grow up?

Question 8 was initially thought to be a valid question for analysis as it could enable the elicitation of responses from respondents reluctant or unable to use their own words to describe what they believe about engineering. However, it was later excluded because researchers were unable to objectively decipher the results. Additionally, this method can only contain a singular image, which may not clearly display the students' full breadth of knowledge about engineering or may elicit a stereotypical response.[14]

Question 9 provides information about which careers the students are interested in and could potentially influence curriculum development to capture their interests. This could in turn help us to broaden their exposure to other careers including engineering. For example, if students indicated careers that focus on helping people, we could explain how engineers contribute to the fields of interests or more directly how engineers help people. The responses to this question are not considered to be a direct reflection of the students' perception of engineering per se.

In order to conduct quantitative analysis of the open-ended results, responses were categorized. Percentage responses in each category were calculated to generate frequencies of responses. Responses from students who provided more than one answer to a question were tallied separately to report the full range of responses.

A second set of entrance and exit closed-ended surveys was administered primarily to assess the students' engagement or interest and attitudes toward STEM. A copy of this instrument is included in Tables 4 - 6.The questions in the closed-ended survey are aimed at discovering the level of short term or long term interest, or feelings that respondents hold with regard to engineering, math and science. This survey contained twenty items with a four-point Likert scale response format. Students could rate each item from one (which indicated "strongly disagree") to four (which indicated "strongly agree"). Analysis of these results was performed by generation of frequencies of responses in each category and by the weighted average responses for each question in order to gage the feeling of the entire sample population. Responses of agreement and disagreement were also respectively pooled and evaluated in Table 6, as it was not clear that students were capable of delineating between the choices. Blank answers were not counted in this analysis. Surveys were administered anonymously. Questions were read aloud for students to avoid difficulty in understanding them.

Student survey results are presented from a 5th grade science class, who worked with an African American, female, Environmental Engineering doctoral candidate and from a 6th and 8th grade class in an engineering design elective, who worked with a Hispanic, male, Biomedical Engineering doctoral candidate for the duration of the academic year. We present the results of a total of 102 surveys, obtained at the beginning of the academic year and 79 surveys, collected at the end of the class. The surveys were administered to the same classes at the beginning and end of the academic year. The decline in surveys collected at the end of the year is a result of several factors including changes in enrollment, attendance, and participation. See Table 1 for a breakdown of respondents at the beginning and end of the academic year by grade. This group is a random sample of students participating in this NSF GK-12 program with Drexel University in Philadelphia, PA and represents only a fraction of the total population of students (2/9 classes) impacted by the program. Similar trends were observed in the data from both student groups and this was the basis for aggregating the results reported in this paper.

The overall program during the 2008-2009 academic year consisted of nine teaching fellows who served a total of approximately 300 students in grades 5-8 from 7 public middle schools within the School District of Philadelphia. The engineering disciplines represented by the fellows included electrical and computer, mechanical, civil and environmental, materials science, and biomedical. Fellows were assigned to a school and class(s) at the assigned school for the entire school year, representing 9 parallel interventions. The school district is among the 10 largest in the United States. In 2008, the district had a total enrollment of 163,064 in grades K-12 and 79% of those students belonged to groups of underrepresented minorities in the STEM fields (African American, Hispanic, or Native American). From the students who took our survey 97% were of racial or ethnic minorities.

Table 1 – Total Number of Entrance and Exit Survey Respondents by Grade

Grade	Entrance	Exit
5th	30	16
6th	38	33
8th	34	29

Interventions

The 5th grade participants were in a self contained class with a single teacher for all academic subjects. The fellow primarily focused on bringing engineering context to the District prescribed science curriculum. However, some concepts in mathematics were also emphasized. A primary goal of the science curriculum was the understanding and implementation of the scientific method through a number of activities divided into three 12 week thematic modules: Solar Energy, Variables and Ecosystems. The fellow developed several new lessons to incorporate engineering concepts into the curriculum[15]. A sample of the new lessons and concepts include: 1) "Is it really full?" - Capacity vs. volume, 2) "Solar Water Heaters: Fact or Factor" - Experimental design, and 3) "Big Bottle or Tested Tap" - Ecological impacts of consumer choices. Additionally, she identified and supplemented the curriculum with purely design based activities like "Bottle Rocket Cars"[16] and "Paper Towers"[17]. Furthermore, as general practice she modified the required lessons to focus on analytical skills: data collection, analysis, interpretation, prediction and application. A summary description of the concepts from the above mentioned lessons follows:

1) Is it really full?

Students measured volume and capacity, with materials used by civil and environmental engineers for water filtration. They graphed their findings and determined the relationship between grain size and porosity. These material properties are important deign considerations for both civil and environmental engineers.

2) Solar Water Heaters: Fact or Factor

As part of the science curriculum (Full Option Science System (FOSS), http://www.fossweb.com/) students completed construction of two water heaters to determine factors influencing the amount of heat that can be stored. Using the FOSS activity as background, students were presented with an engineering research question and instructed to vary three different factors – size of the collector, color of the collector and whether the heater is covered or uncovered. The goal of this lesson was to differentiate how engineers use and design experiments for research as part of the design process to optimize performance of a device.

3) Big Bottle or Tested Tap

The goals of this activity were twofold. First students were introduced to some measurable indicators of water quality through the use of testing strips. They used both the measurable indicators as well as their own assessment of taste and odor to rank several types of water. Then students were asked to consider a life cycle assessment (LCA) approach to compare bottled water and tap water. The goal of LCA is to compare the full range of environmental and social damages associated with a product or service to be able to choose the least burdensome one.

4) Bottle Rocket Cars

Students acted as mechanical engineers in order to design a rocket car using empty soda bottles, straws, and balloons primarily. The goal was for students to use their intuition to design the cars without the aid of the teacher. By allowing the students to repeat the activity, they were introduced to the iterative design process and able to apply knowledge from the first trial to improve their design.

5) Paper Towers

In this activity, students were given a fixed number of newspaper sheets, a construction paper base, and unlimited amounts of tape to construct the highest and strongest structure they could. The designs were evaluated by a wind test - the teacher turned on a fan to mimic wind, and students were able to see how well their structures withstood shear (wind) force. Tower designs were ranked on both the height and durability criteria.

The 6th and 8th graders who participated in the survey were enrolled in a robotics technology course which focused on four main units: simple machines, range of motion, electricity and modern technology. The GK-12 fellow involved in the class developed activities to relate the concepts of each unit and introduce engineering disciplines along the way[18]. Samples of the lesson themes are as follows: 1) Levers in the human body, 2) Overcoming friction with wheels and axles, 3) Designing a bionic arm, 4) Arm power, and 5) Building an electrical motor. In each activity design, data collection, and interpretation of results were important criteria for the successful completion of the assignment. Engineering themes of some of the lessons are described as follows:

1) Levers in the human body

In this activity students learned how to identify the three classes of levers found in the human body. They had to build a first class lever system and record the amount of force needed to lift a weight at various distances from the fulcrum. After graphing their data students had to comment on the relationship between force and distance as they relate to work.

2) Arm power

In this activity students learned about the physical concepts involved in lifting weights by calculating the average amount of work and power needed for your muscles to complete an arm curl activity. They were also taught the importance of repeating an experiment so that they could report more accurate results.

3) Designing a bionic arm

In this activity students learned about the engineering design process by building a prototype of a mechanical arm that could be used by people who have lost upper limbs to pick up a cup of water and drink it without spilling it. Here students identified the problem, brainstormed their design ideas, sketched a technical drawing, built their prototype, and then presented its effectiveness in front of the class.

4) Overcoming friction with wheels and axles

In this activity students were introduced to friction by using spring scales to measure the amount of force needed to move an object across a rough surface. They had to calculate the coefficient of static friction of various surfaces found in the classroom (floor, rug, table top, etc). Later students had to design a rolling structure that could easily overcome static friction and move the teacher across a distance of 2 meters in the shortest time.

5) Building an electrical motor

In this activity students learned about electricity and magnetism by building a motor using a battery, magnet and wire. Students had to make a set of three motors by coiling the wire differently every time. Based on the number of turns students determined which was the best design for a motor.

Results

Survey responses at the beginning of the school year revealed students overwhelmingly defined an engineer as ‘a person who fixes things.’ They could not identify specific tasks or problems solved by engineers or any of the technological tools that engineers use. Students did not personally know an engineer and could not identify more than one type of engineer.

Question 1: What is an engineer?

Initially, when asked to explain what an engineer is, most students (58%) used common words such as “build” or “fix”. These responses primarily referred to building construction or automotive mechanics. The findings were not surprising as they are consistent with previously published assessments of elementary students’ perceptions of engineering.[14] A small percentage (11%) associated the engineering field with computers or technology and an even smaller group (4%) identified math and science as a part of the engineering profession. Initially there were no students, who associated problem solving or design with engineering (Figure 1).

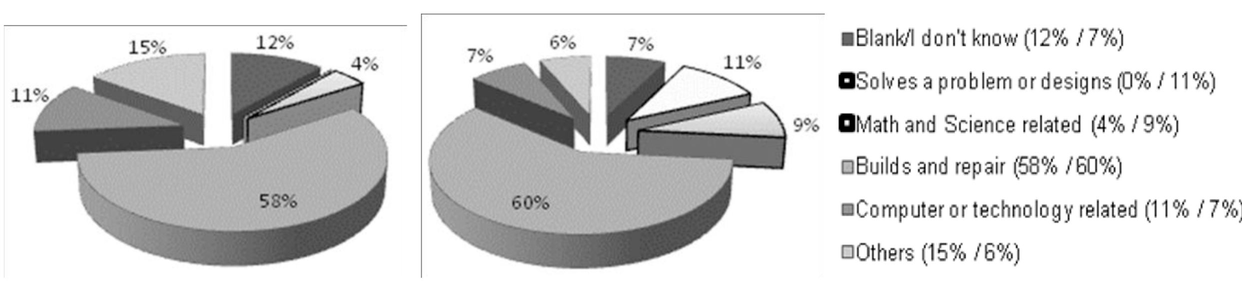

Figure 1: Middle school student responses to the question "What is an engineer?”. The left chart shows responses to the entrance survey and the right chart shows responses to the exit survey.

The exit survey shows more than half of the students still identified engineers as people who build or fix things. The result was not significantly different than the entrance survey responses. However, some improvement was observed. There were students (11%), who were able to identify engineers as problem solvers or designers in contrast to 0% in the entrance survey. The number of students who associated engineering with math and science doubled (9%), which demonstrated progress towards a more accurate perception as well.

Question 2: What does an engineer do?

Question 2 captures some of the same ideas that Question 1 attempts to capture, so we did not expect significantly different responses. About half (48%) of students identified building or repairing as tasks associated with engineering. Answers more specifically mentioned "car and truck related mechanic tasks" (21%). There were no students who associated math and science as part of the engineer's job, but a few students (1%) used words such as "invent" and/or "design" or thought that engineers were problem solvers (Figure 2).

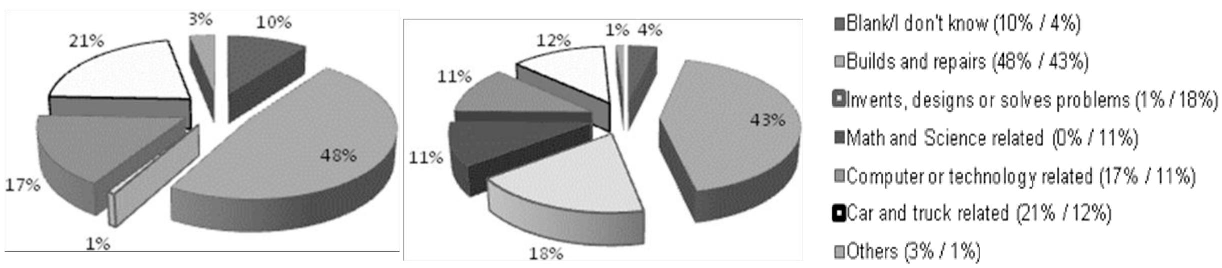

Figure 2: Middle school student responses to the question "What does an engineer do?". The left chart shows responses to the entrance survey and the right chart shows responses to the exit survey.

At the conclusion of the program, fewer students (43%) believed that engineering was associated with skilled trades like contractors or repairmen, which some described as "working with their hands". This number dropped by 5%. Interestingly there was a decline in student responses identifying automobile and truck repair as an engineer's job (from 21% to 12%). This indicates that after working with a GK-12 fellow, some students realized engineers did not strictly do work related to automobiles. Additionally, many more students began to associate engineering careers with designing things or solving problems (18%) and with math and science (11%). There were 17% and 10% increases respectively.

Question 3: How does a person become an engineer?

The responses to question 3 revealed how well students understood the education requirements of the engineering profession (Figure 3). Most students indicated that education was a requirement for becoming an engineer although their responses varied in specificity. The responses "going to college" and "getting a degree" were considered individually because the answers to the entrance surveys indicated that students were not clear about what type of schooling was needed to become an engineer. Some students identified "attending ITT tech" or "staying in school" as plausible ways to becoming an engineer. However, by the end of the school year, the frequency of responses became more concentrated around attending college and earning a degree, with increases of 16% and 11%, respectively. At the same time, the number of students who simply responded "going to school" or "getting an education" decreased by 8%. Categories such as doing well in math and science, working hard, and other, decreased by a combined 7 percentage points. This indicates that students began to realize that higher level education was a specific requirement for becoming an engineer.

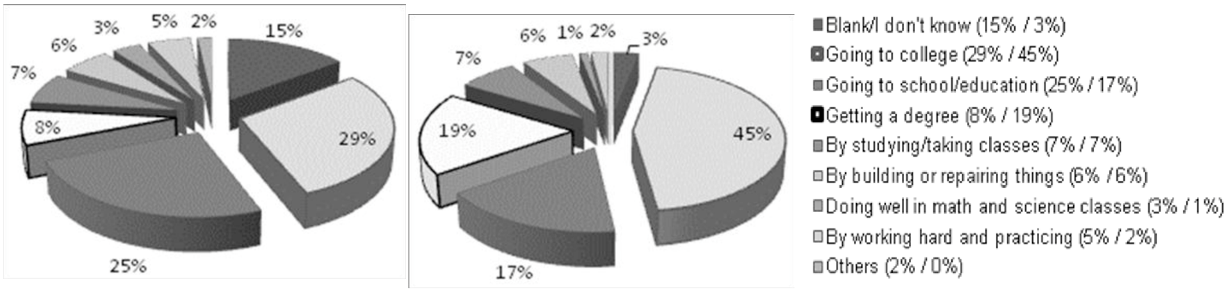

Figure 3: Middle school student responses to the question "How does a person become an engineer?". The left chart shows responses to the entrance survey and the right chart shows responses to the exit survey.

Question 4: Name 3 types of engineers.

Table 2 summarizes the responses to "Name 3 types of engineers.". Answers were categorized into the engineering related, non-engineering related, math or physical sciences, and computer or technology related. Responses in the engineering related category included the traditional disciplines such as mechanical, electrical, chemical and civil engineering but also the sub-disciplines such as aerospace, biomedical, environmental, materials engineering, etc. The non-engineering related category included anything that was not an engineering discipline, for example skilled trade positions, medical professions and civil service jobs except for those that were computer or technology related.

The entrance surveys reveal that only 33% of students identified an engineering discipline. At the conclusion of the year 63% of students could name types of engineers. This is a significant increase, however it is unclear if the improvement was a matter of learning the vocabulary or the development of a diverse understanding of the engineering disciplines.

Table 2 – Responses to Question 4: Name 3 types of engineers.

Name 3 types of engineers	Entrance	Exit	Change
Engineering related	33%	63%	30%
Non-engineering related jobs (Includes car/mechanics)	31%	15%	-16%
Science and Math related jobs	8%	3%	-5%
Computer and technology related jobs	5%	8%	3%
Left blank or stated "I don't know"	21%	8%	-1%
Others	2%	3%	1%

Question 5 "What tools does an engineer use?"

Table 3 summarizes the responses to Question 5. There was resounding agreement (73%) in the entrance surveys that shows students associate engineering tools with those related to the skilled trades. This demonstrates the deeply held misconception that engineers are skilled workers. The responses in this category included hammers, metal, wood, wrench and electrical wires. The exit survey showed a decrease of 26% in these responses.

The exit survey also showed an increase in responses relating to computer/technology and robotics (+12.4%), telescope/microscope (+16.2%), and lab equipment (+8.6%). These results were largely based on the tools students used in their classes with the activities the fellows developed during the school year.

Table 3 – Responses to Question 5: What tools does an engineer use?

What tools does an engineer use?	Entrance	Exit	Change
Skilled worker tools including electronics	73%	47%	-26%
Computers, technology and robotics	6%	18%	12%
Classroom equipment	3%	0.5%	-2%
Telescope and Microscope	0.0%	16%	16%
Chemicals and Laboratory equipment	0.5%	9%	9%
Left blank or stated "I don't know"	15%	6%	-9%
Others	2.5%	2.5%	0.1%

Question 6: Do you know any engineers?

The entrance survey revealed that few students indicated they knew engineers initially, while 44% of students said that they did not know an engineer. Some students (12%) stated that they had a family member who they considered an engineer, and 10% knew an engineer who was not their family member, for example neighbor, building engineer at school, etc. At the conclusion of the year, the exit surveys had a slight decrease in the student responses identifying their family members as engineers (-4%). This indicates that a few of the students could have realized their description of an engineer was not correct – a change in their perception of what an engineer is perhaps.

Students had been introduced to the GK-12 teaching fellow for one class period prior to completing the surveys, but interestingly only 13% identified the fellow as an engineer they knew during the initial assessment. The exit survey revealed that about half (51%) considered the fellow to be an engineer that they knew.

Question 9: What would you like to be when you grow up?

While this question was not part of the analysis, the results are reported because they could lead to better designed activities to capture students' interests. The students provided a variety of answers to this question. During the entrance surveys, the top three most frequent responses were 1) "I don't know" (21%), 2) a medical related profession (20%), and 3) an athlete (17%). The exit surveys showed similar commonalities with the top four most common responses being 1) an athlete (23%), 2) undecided (17%), 3) a star or entertainer (13%) and 4) a medical field related profession (12%).

The most significant finding for this question was that the category for becoming an engineer increased by 5.6%. Small percentages of students (2% each) indicated that they were interested in being a mathematician/scientist or an engineer initially. The final surveys had no responses in the mathematician/scientist category. It is unclear whether these are the same students who narrowed their choices toward engineering.

For all questions in the exit surveys, there were fewer responses left blank or answered with "I don't know." This could mean that the students became more comfortable sharing their thoughts or now had developed a response to the question.

Close ended surveys

Results of the close-ended survey are tabulated in Tables 4-6. An initial analysis was conducted by comparing the weighted averages of responses in each survey. Responses that deviated from the mean by more than 0.5 were considered significant in this analysis.
In the entrance survey, 7 questions showed significant agreement or disagreement (Questions 2, 3, 6, 11, 14, 16, and 17). Students showed strong agreement that science and/or math are important outside of school. Students indicated that they would prefer computers and science equipment for math and/or science education over books.

Most students did not believe that engineering is boring. They strongly agreed that women can succeed in engineering as easily as men. They also agree engineers play an important role in solving society's problems even though they are not clearly aware of which problems or consider engineers as problem solvers. Most students agreed that finding a job with an engineering degree would be easy.

The exit surveys showed similar results to the entrance surveys, particularly for the 7 questions considered as demonstrating significant agreement or disagreement. There were two questions where the group students changed their opinions were Question 16 and 17. There was less concurrence about the importance of the role of engineers in solving society's problems and if they would have trouble finding a job with an engineering degree. The decrease in these questions probably has more to do with the current economic recession than with the activities developed during the school year. Students are aware of a high overall unemployment rate.

There were a several questions in both the entrance and exit surveys where 40% or more students had concurrence among their responses. These might be considered generally held perceptions. In the entrance survey these questions were Questions 2,3,5,6,7,11,14,15,17,19. Of these questions, the exit survey showed strong agreement ($\geq$ 40%) with a given response only to Questions 2, 3, 5, 6, and 11. All other questions had responses that indicated a spread of opinions amongst the group and less of a consensus. For example, more than half the students (55%) indicated that they liked using computers for learning science and math rather than books.. Students appeared to develop more individual opinions to Questions 7, 14, 15, 17, 19, as indicated by the spread of responses amongst the four categories.

Because there was so much disparity among most responses, the responses to all questions were aggregated to form only two categories – agree or disagree (see Table 6). By doing this, we were able to more clearly identify if any significant changes in perception occurred. Most questions did not indicate any significant changes in perception (<6%), with the exception of Questions 10, 17 and 19. Question 10 asked students if they were considering studying math and/or science in high school. Initially 72% of students agreed with this statement. At the end of the academic year, 62% still agreed. Question 17 showed an 11% reduction in agreement. Students no longer agreed as much that having an engineering degree would lead to finding a job. Again, we believe this result is confounded with the current economic recession and high unemployment rate. Question 19 asked if students thought that engineers spent a lot of their time working with computers. There was a 19% reduction in students who agreed with this statement. This was our most significant finding. Students began to dissociate using a computer with the practice of engineering. Additionally, fellows described their laboratory experiments in greater detail than their analytical and written computer work trying to focus on hand-on activities to stimulate interests in engineering.

Discussion

The focus of this paper was to assess and track changes in perceptions about engineering in middle school students participating in an NSF GK-12 program after 1 year of interaction with an engineering graduate student fellow. The results of our surveys support the overwhelming conclusion that students have misconceptions about what engineering is and what engineers do. This is not an isolated misconception held only by students, the general public and even many teachers share this position.[19] The field of engineering has rapidly changed in recent years and has become so diverse in scope that consensus on a definition would be hard to come by even amongst professionals. Since a conception in the minds of the middle school students is what we ultimately hope to accomplish through this educational intervention, it is necessary to identify this end result in order to evaluate the effectiveness of our parallel interventions as it should be the basis of the educational activities implemented.[20] Schunn presents a general definition that describes engineering as using analytical and empirical processes to design complex systems that meet stated objectives and take into account specific scientific and societal constraints.[4] The American Engineers' Council for Professional Development (ECPD, the predecessor of ABET, Accreditation Board for Engineering and Technology) defined engineering as follows: "The creative application of scientific principles to design or develop structures, machines, apparatus, or manufacturing processes, or works utilizing them singly or in combination; or to construct or operate the same with full cognizance of their design; or to forecast their behavior under specific operating conditions; all as respects an intended function, economics of operation and safety to life and property." [21] Both a fine definitions. However, for the middle school student, our goal was much less sophisticated although we hoped to plant the seeds necessary for the students to develop more complicated definitions such as these using their own words, after greater exposure to engineering. The authors considered a developmentally appropriate definition for this group to be one that encompassed the use of higher level math and science to solve everyday problems. The activities focused on some of these problems and touched the surface of a few techniques that engineers use to solve these issues.

The top student responses to questions "what is an engineer?" and "what do engineers do?" were all grounded in ideas that focus on automotive mechanics or building construction. This was further reinforced by responses to "what tools does an engineer use?" A majority of students identified tools used by skilled workers. These misconceptions are so deeply held that they remained even after a year in the GK-12 program, but this isn't the whole picture.

On the other hand, some progress was made toward changing students' perceptions throughout the program as some students were able to associate design and problem solving with engineering and fewer students specifically stated car or truck related repair work. Respondents also began to identify higher education (specifically attending college and earning a degree) as a requirement for becoming an engineer.

The exit surveys and the close ended questionnaires reveal that having an engineer fellow in the classroom had a positive influence on the perception of engineers. By the end of the year, 50% of students identified the fellow as an engineer and more students understood the requirements to becoming an engineer. It is important to note that the fellows were not placed in the classrooms with the purpose of teaching the students how to become engineers but rather to develop lessons and activities that would expose students to engineering concepts, while stimulating interest in math and science.

It is recognized that changing perceptions and misconceptions present challenges beyond the scope of this paper and that knowledge and performance also present barriers to the pursuit of STEM careers. We suspect that a key factor influencing this population is the lack of role models or people students identify as engineers. Final responses indicated improvement in this area as students began to identify the fellow as an engineer that they personally knew. We consider this a positive gain with a caveat since the fellow only represents one engineering discipline and at the PhD level is more of a researcher than a practitioner. Although students showed growth in the ability to identify more engineering related fields at the end of the year, they did not indicate a greater understanding of what engineers actually do. An activity designed to introduce the breath of engineering disciplines may provide for greater understanding. We also suggest that programs like this consider rotating fellows from different disciplines through each classroom to aid in this regard. Some background about engineering research and engineering practice could serve to diffuse potential misconceptions. Introducing the students to practicing engineers in addition to fellows, who primarily conduct research, could also help to avoid misconceptions about what engineers do in practice. While there is a design component to good research, it is less tangible then the work of practicing engineers.

Students' final responses indicate they were impacted by the specific activities implemented by the fellows, as well. They changed their perception of what tools engineers use based on the tools they used during the program. The closed-ended responses also indicated that they believed engineers used computers most of the time, but to a lesser extent after working with fellows, based on the actual activities they did with the teaching fellows in class. As often as possible fellows talked about their own research and disseminated it into their classes to as much of an extent as deemed appropriate, given that developing the communication skills of the graduate students in the GK-12 Program is a major goal of the National Science Foundation (NSF.) The experimentation components of the fellows' research were primarily emphasized in comparison with the analysis and computation portion and we presume this also had an impact on changes in perception. It seems that both the students' understanding of the fellows work and the tools and equipment they used in activities designed or chosen by the fellows had the greatest influence on them. This is a significant finding that should shape the choice of lessons and activities in the future. This finding also points to the need to rotate fellows from different disciplines through the classrooms or otherwise ensure that the students are exposed to a variety of engineers.

Conclusions

The results of the open-ended survey reveal that there are misconceptions about the engineering profession among underrepresented minority middle school students. However, this population is not defining engineers as train conductors as is the common stereotype. In fact the word train was only used once in the context of a person who fixes "cars, trucks or trains." Instead our survey reveals that most students believe engineers perform work and use tools related to construction or the skilled trades. With carefully designed materials and lessons, this perception could be transformed if the connections between design and construction or manufacturing are emphasized in a project based format.

We report the results of a small heterogeneous sample of the population involved in the NSF GK-12 Program at Drexel University. Similar trends were observed in the responses from both groups. However, one group of students was introduced to engineering through integration into the science curriculum and the others were taking a design elective in robotics. Since true engineering, as defined by Dr. William Wulf, Past President of the National Academy of Engineering, "…is design under constraints" it is important to determine how these two methods influenced the students' perception of engineering separately. Thus, future work should include a larger population and disaggregated data to illustrate whether differences in the two approaches have an effect on the students' perceptions of engineering. Based on the results of the design focused activities we introduced through this intervention, we unfortunately found that 'design' for the students generally takes the form of 'trial and error.' This could clearly lead to further misconceptions about the meaning of 'engineering,' so the assumption that engineering design based interventions are automatically superior to engineering science based educational initiatives would not be appropriate.

Engineering in the K-12 classroom should not be the following[3]:
1) Using technology to take data or demonstrate a science concept, since this requires very little technical know-how about the science or math principles governing the processes involved;
2) "Trial and error", since this neither requires the student to know, learn or integrate complex information, scientific or mathematical principles; or
3) "A cookbook process" because true engineering is innovative and requires adaptation and creativity.

The gains tracked from our surveys suggest that implementing engineering activities into science and math curricula or separately as a design elective both have a positive effect on the understanding of engineering, but will require improvement to counter preconceived misconceptions in certain populations. We recognize that the debate on which approach is best is still open, but pre-eminently concur with the findings of Schunn, which encourage (1) engaging children in solving significant design problems from the beginning; (2) making visible models to support the design task; (3) allowing students to experience iterative design and redesign as opposed to a single design cycle; and (4) providing sufficient time for exposure to engineering material[4]. A common thread between all of these findings point to longer term, project based and design focused activities that expose students to the practice of engineering while allowing them sufficient time to comprehend the complexities of the material. We believe that with planning this could be achieved under both approaches employed by the fellows in this paper.

In addition to the application of scientific and mathematic principles to solve problems, engineering involves a non-linear thought process that should be emphasized in the activities presented through programs to increase engineering exposure and technical literacy. At a minimum, activities should involve all the steps of the cyclical engineering design process: understanding the need through a set of objectives and criteria, brainstorming, integrating ideas, design, evaluating the design against the criteria, construction, testing, re-evaluation, re-design. Establishing the difference between this process and for example the scientific method should be an early step to avoiding deeper misconceptions, when engineering is introduced into science curriculum. Further, emphasizing the practicality of using this process to solve everyday problems can help to reinforce the correct perception of engineering and as a result increase interest in engineering [22]. We believe that longer term studies to track the impacts of these programs should therefore measure whether the seeds planted through these activities have an effect on how the students think and approach problems.

In the future, we would recommend an interview component so that each student is asked the questions one on one. This would remove the temptation of copying each other's responses and also give students who have difficulty reading a higher probability of comprehending the questions. With regard to survey design, the open ended survey can be redesigned into a multiple choice survey. Students are more familiar with this style of evaluation as a result of increased, state and local mandated testing. The pilot data from this study will be used to form categories that can capture the overall perceptions of a larger student population better enabling our program to track its effectiveness.

Table 4 – Responses to Close-ended Entrance Survey

Question #	Entrance Survey				
	Percentage of Student Answers in Each Category				Weighted Average
	Strongly Agree (4)	Agree (3)	Disagree (2)	Strongly Disagree (1)	
1. I like to watch TV shows about science and/or math.	11%	32%	28%	28%	2.3
2. I think science and/or math is important even out of school.	48%	34%	8%	9%	3.2
3. I would rather use computers to learn about science and/or math than read a science and/or math book.	55%	26%	15%	4%	3.3
4. Science and math tests make me nervous.	30%	27%	18%	25%	2.6
5. Science and math are fun.	20%	48%	20%	11%	2.8
6. I like to use science equipment to study science better than reading science books.	49%	24%	16%	11%	3.1
7. My mind goes blank when I am doing science and/or math.	16%	17%	28%	40%	2.1
8. I am interested in many scientific and math ideas that are not taught at school.	20%	30%	31%	20%	2.5
9. I think that engineering could be an interesting career.	28%	38%	24%	10%	2.8
10. I am considering studying math and/or science in high school.	33%	38%	18%	10%	2.9
11. From what I know, engineering is boring.	15%	11%	31%	43%	2.0
12. Engineers are usually those people who were called "nerds" in school.	21%	15%	27%	36%	2.2
13. I would like to study engineering because it provides more money than most careers.	26%	25%	31%	17%	2.6
14. A woman can succeed in engineering as easily as a man.	40%	33%	11%	15%	3.0
15. Engineers are highly respected by others.	28%	42%	24%	6%	2.9
16. Engineers play an important role in solving society's problems.	37%	34%	22%	7%	3.0
17. I would have no problem finding a job if I had an engineering degree.	30%	41%	23%	6%	3.0
18. Engineers spend a lot of their time working in laboratories.	21%	33%	29%	17%	2.6
19. Engineers spend a lot of their time working with computers.	26%	48%	14%	11%	2.9
20. A career in engineering would leave me time for family and fun.	19%	35%	21%	25%	2.5

Table 5 – Responses to Closed-ended Exit Survey

Question #	Exit Survey: Percentage of Student Answers in Each Category – Strongly Agree (4)	Agree (3)	Disagree (2)	Strongly Disagree (1)	Weighted Average	Change in Weighted Average (Exit - Entrance)
1. I like to watch TV shows about science and/or math.	13%	36%	27%	24%	2.4	0.10
2. I think science and/or math is important even out of school.	57%	26%	16%	1%	3.4	0.17
3. I would rather use computers to learn about science and/or math than read a science and/or math book.	47%	29%	16%	7%	3.2	-0.16
4. Science and math tests make me nervous.	19%	34%	31%	16%	2.6	-0.06
5. Science and math are fun.	28%	41%	26%	6%	2.9	0.12
6. I like to use science equipment to study science better than reading science books.	53%	22%	13%	12%	3.2	0.05
7. My mind goes blank when I am doing science and/or math.	21%	19%	24%	36%	2.3	0.18
8. I am interested in many scientific and math ideas that are not taught at school.	28%	28%	32%	12%	2.7	0.21
9. I think that engineering could be an interesting career.	25%	43%	19%	13%	2.8	-0.05
10. I am considering studying math and/or science in high school.	29%	33%	23%	15%	2.8	-0.18
11. From what I know, engineering is boring.	10%	15%	33%	42%	1.9	-0.05
12. Engineers are usually those people who were called "nerds" in school.	18%	21%	26%	35%	2.2	0.02
13. I would like to study engineering because it provides more money than most careers.	26%	23%	41%	11%	2.6	0.03
14. A woman can succeed in engineering as easily as a man.	37%	37%	13%	12%	3.0	0.01
15. Engineers are highly respected by others.	27%	40%	24%	10%	2.8	-0.08
16. Engineers play an important role in solving society's problems.	29%	36%	20%	15%	2.8	-0.22
17. I would have no problem finding a job if I had an engineering degree.	29%	32%	23%	17%	2.7	-0.23
18. Engineers spend a lot of their time working in laboratories.	21%	38%	25%	16%	2.6	0.06
19. Engineers spend a lot of their time working with computers.	26%	29%	28%	16%	2.7	-0.23
20. A career in engineering would leave me time for family and fun.	25%	28%	30%	16%	2.6	0.14

Table 6 – Pooled Responses to Closed-ended Exit Survey

Question #	Entrance		Exit		Change in Percent Responses	
	Agree	Disagree	Agree	Disagree	Agree	Disagree
1. I like to watch TV shows about science and/or math.	44%	56%	49%	51%	5%	-5%
2. I think science and/or math is important even out of school.	82%	18%	83%	17%	1%	-1%
3. I would rather use computers to learn about science and/or math than read a science and/or math book.	81%	19%	76%	24%	-5%	5%
4. Science and math tests make me nervous.	57%	43%	53%	47%	-4%	4%
5. Science and math are fun.	69%	31%	68%	32%	0%	0%
6. I like to use science equipment to study science better than reading science books.	73%	27%	75%	25%	2%	-2%
7. My mind goes blank when I am doing science and/or math.	32%	68%	40%	60%	8%	-8%
8. I am interested in many scientific and math ideas that are not taught at school.	49%	51%	55%	45%	6%	-6%
9. I think that engineering could be an interesting career.	66%	34%	68%	32%	2%	-2%
10. I am considering studying math and/or science in high school.	71%	29%	62%	38%	-9%	9%
11. From what I know, engineering is boring.	26%	74%	25%	75%	-1%	1%
12. Engineers are usually those people who were called "nerds" in school.	36%	64%	39%	61%	3%	-3%
13. I would like to study engineering because it provides more money than most careers.	52%	48%	48%	52%	-3%	3%
14. A woman can succeed in engineering as easily as a man.	74%	26%	75%	25%	1%	-1%
15. Engineers are highly respected by others.	70%	30%	67%	33%	-3%	3%
16. Engineers play an important role in solving society's problems.	71%	29%	65%	35%	-6%	6%
17. I would have no problem finding a job if I had an engineering degree.	71%	29%	61%	39%	-11%	11%
18. Engineers spend a lot of their time working in laboratories.	54%	46%	59%	41%	5%	-5%
19. Engineers spend a lot of their time working with computers.	75%	25%	56%	44%	-19%	19%
20. A career in engineering would leave me time for family and fun.	54%	46%	54%	46%	0%	0%

Bibliography

1. Committee on the Offshoring of Engineering, N.A.o.S., The Offshoring of Engineering: Facts, Unknowns, and Potential Implications. 2008, Washington, D.C. : National Academies Press.
2. Jackson, S.A., The Quiet Crisis: Falling Short in Producing American Scientific and Technical Talent, Building Engineering and Science Talent (BEST), Editor. 2004.
3. NAE and NRC, Committes on K-12 Engineering Education; National Academy of Engineering and National Research Council., Engineering in K-12 Education: Understanding the Status and Improving the Prospects, ed. L. Katehi, Greg Pearson, and Michael Feder. 2009, Washington, D.C: National Academies Press.
4. Schunn, C., How Kids Learn Engineering: The Cognitive Science Perspective. The Bridge 2009. **39**(3).
5. Jeffers, A.T., Angela G. Safferman, and Steven I. Stafferman, Understanding K-12 Engineering Outreach Programs,. Journal of Professional Issues in Engineering Education and Practice, 2004. **130**(2): p. 95.
6. Chubin, D., G.S. May, and E.L. Babco, Diversifying the Engineering Workforce. Journal of Engineering Education, 2005: p. 73-86.
7. Posner, G.J.S., Kenneth A.; Hewson, Peter W.; Gertzog, William A., Accommodation of a scientific conception: Toward a theory of conceptual change. Science Education, 1982. **66**(2): p. 211-227.
8. Sadler, P.M., H.P. Coyle, and M. Schwartz, , Engineering competitions in the middle school classroom: Key elements in developing effective design challenges. Journal of the Learning Sciences, 2000. **9**(3): p. 299-327.
9. Davis, R.S., I.S. Ginns, and C.J. McRobbie, Elementary school students' understandings of technology concepts. Journal of Technology Education, 2002. **14**(1): p. 35-50.
10. Rose, L.C.G., Alec M.; Dugger, William E., Jr.; Starkweather, Kendall N., The Second Installment of the ITEA/Gallup Poll and What It Reveals as to How Americans Think about Technology: A Report of the Second Survey Conducted by the Gallup Organization for the International Technology Education Association. Technology Teacher, 2004. **64**(1): p. 12.
11. Lewis, T., Research in technology education--Some areas of need. Journal of Technology Education, 1999. **10**(2): p. 41-55.
12. Houghton, W. Engineering Subject Centre Guide: Learning and Teaching Theory for Engineering Academics. 2004; Available from: http://www.engsc.ac.uk/er/theory/conceptions.asp.
13. NSF, Framework for Evaluating Impacts of Informal Science Education Projects Report from a National Science Foundation Workshop A.J. Friedman, Editor. 2008.
14. Cunningham, C.M., Cathy Lachapelle, Anna Lindgren-Streicher. *Assessing Elementary School Students'* Conceptions of Engineering and Technology. in 2005 American Society for Engineering Education Annual Conference & Exposition. 2005.
15. Mitchell-Blackwood, J. 2009; Available from: http://gk12.coe.drexel.edu/modules/doc/Jade_Blackwood/.
16. Johnson, R. 2008; Available from: http://gk12.coe.drexel.edu/modules/doc/Rodney_Johnson/.
17. Kusic, D. 2008; Available from: http://gk12.coe.drexel.edu/modules/doc/Dara_Kusic/.
18. Figueroa, M. 2009; Available from: http://gk12.coe.drexel.edu/modules/doc/Manuel_Figueroa/).
19. Yasar, S., Dale Baker, Sharon Robinson-Kurpius, Stephen Krause and Chell Roberts, Development of a Survey to Assess K-12Teachers' Perceptions of Engineers and Familiarity with Teaching Design,Engineering, and Technology. Journal of Engineering Education 2006: p. 205-216.
20. Wiggins, G.P. and J. McTighe, Understanding by Design, 2nd Edition. 2005, Alexandria, VA: Association for Supervision and Cirriculum Development.
21. Wikipedia, c., Engineering, in Wikipedia, The Free Encyclopedia, Wikipedia, Editor. 2010.
22. Reynolds, B., et al., Increasing Student Awareness of and Interest in Engineering as a Career Option through Design-Based Learning. International Journal of Engineering Education, 2009. **0**(0): p. 1-11.