Carbon Nanotube Composites: Using an Authentic Engineering Research Problem to Engage Middle School Students in STEM

Nancy Warter-Perez, Sevak Ghazaryan, and Jerardo Martin
California State University, Los Angeles/ Stevenson Middle School

Abstract
Since 2008, the IMPACT LA NSF GK-12 Program (Improving Minority Partnerships through CISE (Computer, Information Science & Engineering)-related Teaching) has been partnering graduate teaching fellows with middle and high school science and math teachers within the East Los Angeles area. The Cal State L.A. graduate fellows serve as visiting scientists and engineers who work closely with their partner teachers to engage middle and high school students in science and engineering activities related to the fellows' research. The program goals are to enhance STEM (Science, Technology, Engineering, and Mathematics) curriculum, inform and inspire students about careers in science and engineering, and improve the graduate fellow's ability to communicate their research to a broad audience. In this paper, we present the middle school math classroom activities developed related to one particular fellow’s research on carbon nanotube composites. Using lightweight carbon nanotube composites for a car chassis can increase fuel efficiency, decrease emissions, and maintain the desired properties of the chassis including its structural integrity measured by strength and toughness and its ability to conduct electricity to ground a car in a lightning strike. The activities developed are tied to 6^{th} – 8^{th} grade California math standards and provide students with an opportunity to see how math can be used to solve authentic engineering research problems. Pre and post-surveys were conducted to measure the impact of the visiting engineer/scientist and the research-related activities on students’ perceptions towards engineers and scientists and their desire to pursue a career in engineering or science. The results related to this particular research are presented as well as the results and findings for all fellows during the 2012-13 school year.

Introduction

Innovations in science, technology, engineering, and mathematics (STEM) fields help shape our society and drive our economy[1]. Not only is there a need for more scientists and engineers, many jobs today require that the workers are STEM-capable, meaning that they are able to apply STEM knowledge to perform their jobs. Furthermore, more and more it is becoming important for people in their daily lives to be STEM literate. Even though the demands for quality STEM education are increasing, U.S. students lag behind those from the highest performing nations on international assessments[2]. Moreover, the achievement gap is even greater for underrepresented minority and low-income students[3]. To address these issues, the National Research Council (NRC) report on Successful K-12 STEM Education identified three goals for U.S. STEM education[4]”:

- Goal 1: Expand the number of students who ultimately pursue advanced degrees and careers in STEM fields and broaden the participation of women and minorities in those fields.

- Goal 2: Expand the STEM-capable workforce and broaden the participation of women and minorities in that workforce.
- Goal 3: Increase STEM literacy for all students, including those who do not pursue STEM-related careers or additional study in the STEM disciplines.

Since 2008, the IMPACT LA NSF Graduate STEM Fellows in K-12 Education (GK-12) Program at California State University, Los Angeles has been working to achieve similar goals by partnering graduate teaching fellows with middle and high school science and math teachers within the East Los Angeles area[5-8]. IMPACT LA Graduate fellows conduct Master's thesis research in a wide array of STEM disciplines, which over the years have included Computer Science, Computer/Electrical Engineering, Bioinformatics, Biomedical Engineering, Mechanical Engineering, Civil Engineering, Biology, Chemistry, and Physics. Fellows work in their partner teacher's classroom as visiting scientists and engineers for 10 hours per week throughout the entire school year. In the classroom fellows present their research, conduct research-related activities, talk about their college experience, and assist the teacher through lectures and other activities. The students also visit the Cal State LA campus during the IMPACT LA Open House where they are able to visit their fellow's research lab, see other fellows' labs, learn about pathways to college, participate in a fun engineering challenge, and hear about different engineering and science careers from industry representatives.

In this paper, we present the classroom activities developed for a middle school math classroom that are related to a mechanical engineering fellow's research on carbon nanotube composites. The activities developed are tied to 6^{th} – 8^{th} grade California math standards and provide students with an opportunity to see how math can be used to solve authentic engineering research problems. Pre and post-surveys were conducted to measure the impact of the visiting engineer/scientist and the research-related activities on students' perceptions towards engineers and their desire to pursue a career in engineering or science. The results related to this particular research will be presented as well as the results and findings for all fellows during the 2012-13 school year.

Carbon Nanotube Composites – An Authentic Research Problem

Overview. The main objective of this research project is to create composite materials with a carbon nanotube matrix that will replace more conventional metal alloys. Carbon nanotubes are known for their great structural properties and preliminary research shows that they can increase the strength of any given composite material more than 30%. The composite under study consists of three parts epoxy and one part hardener with single walled carbon nanotubes (SWNT) uniformly distributed throughout the mixture. If carbon nanotube composite materials are used to replace the metal alloy chassis currently used in cars these days that would reduce the weight of the car and in turn will reduce gas consumption and emissions.

Bringing research into the classroom through hands-on activities. Five activities were created to bring the research on carbon nanotube composites into the classroom. Through these activities, students can gain an appreciation for the difference between strength and toughness and how to measure these traits in a composite material; the conductivity of graphite; design trade-offs when utilizing composite materials; the corrosion-free property of carbon nanotube composites; and the molecular structure of a carbon nanotubes to gain an understanding how a hexagonal structure can be strong. These activities were conducted with 6th through 8th grade mathematics students in varying math courses including: Math 6, Math 7, Algebra 1, and Geometry. These lessons not only demonstrate to the students the benefit of using carbon nanotube composites for car chassis, they also teach students important math concepts based on the mathematical common core standards9 as shown in Table 1.

The lesson plans and supporting material for these activities, along with lesson plans from other fellows, can be found at the IMPACT LA NSF GK-12 website[10]. The descriptions of the activities below are based on the content of the lesson plans which are written for middle school teachers and their students. To assist the teachers and students, the lesson plans have keyword definitions to define important and perhaps unfamiliar terminology (the keyword definitions are not provided here). There are combinations of short and long lesson plans available on the website, where the long lesson plans provide deeper coverage of the background material to help teachers understand and present the material.

Strength vs. toughness activity. When an engineer designs a product, they need to select materials that are safe and cost effective. For example, a car body is traditionally made from metal alloy, because it needs to be strong and safe, however it's also expensive. Composite materials are often more affordable and can be used as a replacement for metal alloys in some products. How do engineers decide if a given composite material can be used to replace a conventional metal alloy? Engineers conduct strength and toughness tests on the composite materials. If the test results show that composite material demonstrates strength and toughness equivalent to metal alloy, then the composite can be used as a replacement.

Between an egg and a lime, which one is tough and which one is strong? In this activity, students conduct stress and toughness test on a lime and an egg. For the toughness test, students drop an egg and a lime from a given height and observe that only the egg breaks, but nothing happens to the lime. This observation shows that the lime is tough enough to take on the forces exerted by the floor.

Table 1. Mapping the classroom activities to Common Core State Standards (CCSS) in mathematics[6] for grade levels 5 through 7.

	Strength vs.	**SWNT Flashlight**	**Composite Rocket**	**Hydrolysis**	**Molecular Structure of Carbon Nanotubes**
Measurement and Data					
CCSS.Math.Content.5.MD.A.1 Convert among different-sized standard measurement units within a given measurement system (e.g., convert 5 cm to 0.05 m), and use these conversions in solving multi-step, real world problems.		✓		✓	✓
Ratios and Proportional Relationships					
CCSS.Math.Content.6.RP.A.1 Understand the concept of a ratio and use ratio language to describe a ratio relationship between two quantities.	✓	✓	✓	✓	✓

CCSS.Math.Content.6.RP.A.2 Understand the concept of a unit rate a/b associated with a ratio a:b with b ≠ 0, and use rate language in the context of a ratio relationship.	✓	✓	✓	✓	✓
CCSS.Math.Content.6.RP.A.3d Use ratio reasoning to convert measurement units; manipulate and transform units appropriately when multiplying or dividing quantities.		✓		✓	✓
CCSS.Math.Content.7.RP.A.1 Compute unit rates associated with ratios of fractions, including ratios of lengths, areas and other quantities measured in like or different units.	✓		✓	✓	✓
Geometry					
CCSS.Math.Content.6.G.A.1 Find the area of right triangles, other triangles, special quadrilaterals, and polygons by composing into rectangles or decomposing into triangles and other shapes; apply these techniques in the context of solving real-world and mathematical problems.					✓
CCSS.Math.Content.6.G.A.4 Represent three-dimensional figures using nets made up of rectangles and triangles, and use the nets to find the surface area of these figures. Apply these techniques in the context of solving real-world and mathematical problems.					✓
CCSS.Math.Content.7.G.B.6 Solve real-world and mathematical problems involving area, volume and surface area of two- and three-dimensional objects composed of triangles, quadrilaterals, polygons, cubes, and right prisms.					✓

For the strength test, a tensile/compression machine, TCM200, is used to calculate how much load it takes to break an egg and a lime. The results are displayed by graphical means as shown in Figure 1. The x and y axis of the graph, display time and load respectively. Based on the graph students should be able to identify the amount of load it takes to break an egg and a lime. If a TCM200 tensile machine is not available for strength testing, teachers may use books as weights for strength test. To give students experience reading graphs, sample graphs from a TCM200 machine are provided as shown in Figure 1.

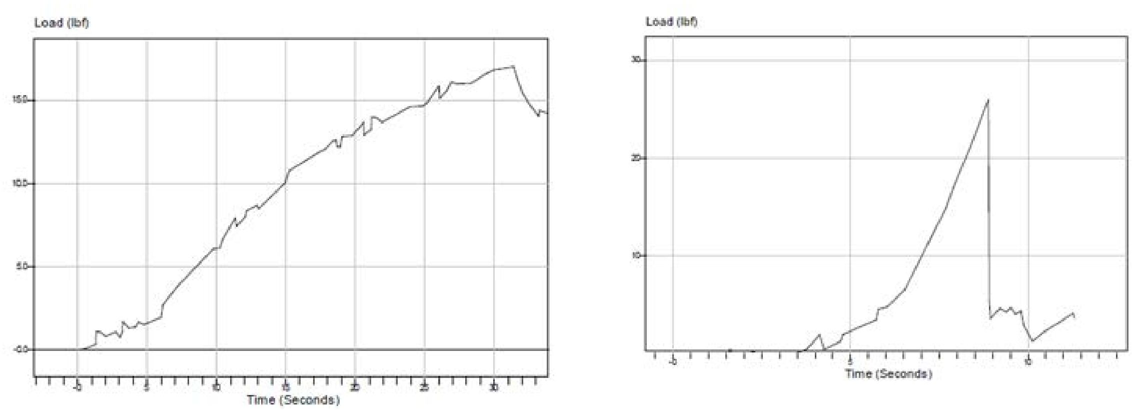

Figure. 1. Students use graphs to analyze how much load it takes to break a lime (left) and an egg (right).

Conductivity of graphite (SWNT flashlight) activity. Almost all mechanical devices starting from household appliances to space technology such as satellites are controlled electronically. To control such devices engineers and scientist use circuits ranging from simple electric circuits to complex computers, which can compute millions of calculations in a matter of seconds. Until recently computer circuit boards used copper, silicon and gold to transfer electrical current and signals throughout the circuit board, because these materials have relatively low resistance to electrical current. Engineers and scientist are always looking for new materials with which they can make new computers with faster processing speed. One such material is graphite. Graphite and single wall carbon nanotubes (SWNT), which are made from graphite, are slowly and surely finding their place in computer technology, because they have very little resistance to electrical current. In addition, the conductivity of carbon nanotube composites is desirable for car chassis so that it can conduct electricity to ground during a lightning strike.

In this activity students observe and understand how electrical current can be transferred through graphite. Figure 2 shows a simple electrical circuit made from an index card, light emitting diode (LED), wires and a battery. As the end of the white wire touches the end of the yellow wires students see the light turning on. There are also three lines with different lengths, which are drawn by a regular HB pencil. When the white wire touches one end of the long graphite line and the yellow wire touches the other end students observe the LED light turn on. Furthermore, as students test all the three graphite lines in decreasing order they will notice how brightness of LED light will increase. The HB pencil is graphite and it is conducting electricity. Shorter length graphite lines have less resistance to current flow and so the LED shines brighter.

Figure 2. Students study the conductivity of graphite, calculate the ratios between lengths of the graphite lines and compare with the brightness of the LED, and roll-up their note card to build a simple flashlight.

Composite rocket. The exploration of our solar system heavily depends on vehicles which are specifically designed for harsh environments found in space. One such vehicle is the space shuttle which is made from many different materials. Each of these materials serves a specific purpose to keep the astronauts inside the space shuttle safe. For example, the lower surface of the space shuttle is made from high-temperature silicone tile which protects the shuttle against high temperatures of reentry into earth atmosphere. The upper surface of space shuttle is made from reinforced carbon material to increase shuttle's structural strength for vacuum conditions in space. In this activity students build a rocket made from different materials and then launch it using a compressed air rocket launcher as shown in Figure 3. Students make their rockets from, printing paper that has already been cut into different geometrical shapes, aluminum foil, plastic wrap, scotch and duct tape. First they must build the body of the rocket by aligning and overlapping different shapes of cut printing papers over one another to make a 10" x 10" square sheet. Then they roll that sheet around the half inch PVC pipe to make a hollow cylinder. They may use aluminum foil, plastic wrap, and duct and scotch tape to re-enforce body of the rocket.

After the body is built, students then work on the cone and the fins of the rocket with the material of their choice. The challenge of this activity is to make the lightest and strongest rocket that will travel farthest in the vertical direction. Students calculate the maximum height the rocket reaches during flight using geometry. If the rocket is too heavy it will not travel far and if the rocket is too light it might not withstand compressed air pressure from the launcher. Students are given an opportunity to redesign and rebuild their rockets based on the observations of previous launches, and thus, they learn that the engineering design process is a cyclical process of design, test, and redesign.

Figure 3. Students build a composite rocket using various materials to try to make a lightweight yet sturdy rocket that will survive the launch and attain the highest point during flight.

Hydrolysis. One of the main reasons that transportation vehicles cannot last for a very long period of time is because they are made from metals that are vulnerable to corrosion. Corrosion in metals is a chemical reaction that turns metal into rust. Many metals corrode merely from exposure to moisture in the air. The corrosion process can also be strongly affected by exposure to certain substances such as salt. In parts of the world where salt is used to melt snow off the roads, cars are more vulnerable to corrosion. In this activity students will observe how aluminum foil and copper wire corrode though a process called hydrolysis. As aluminum foil corrodes microscopic holes begin to appear at its surface. By shining a light on one side of the aluminum foil students will observe how light passes through. Corrosion in copper wire is much easier to identify, since copper changes color to turquoise green as it corrodes and becomes thinner. Through the process of hydrolysis engineers and scientist can determine how long a vehicle can last under different environmental conditions. One way that engineers can make vehicles last longer is by replacing the metal alloy components of the vehicle by moisture and chemical resistant composite materials such as plastics. Plastics composites are highly resistant to water and many other chemicals present in our environment. After all, we buy water from grocery stores in plastic bottles and not metal.

Molecular structure of carbon nanotubes. Engineers and scientists use models to help them analyze the design of structures. For example if civil engineers want to analyze a new bridge design they make a microscale model of the bridge. The microscale model of the bridge allows engineers to conduct experiments on the bridge to confirm design concepts and identify any design flaws before spending millions of dollars on building the actual bridge. Scientists and engineers use macroscale models to study objects, such as molecules, that are too small to be seen by the naked eye. Single walled carbon nanotube (SWNT) is a fairly new material recently introduced to engineering and science fields which is gaining popularity due to its strong molecular structure. In order to better understand SWNTs scientist use Scanning Electron Microscopes (SEM) and Transmission Electron Microscopes (TEM) to study the molecular structures of SWNT. Scientists then use the microscale images of SWNT to make macroscale models in order to better visualize and analyze its molecular structure.

In this activity, students design, build and analyze the molecular structure of a single wall carbon nanotube (SWNT). Students learn that the strength behind the SWNT is its molecular structure which is in the shape of a hexagon. To start out the activity, students are challenged to create a hexagon using geometrical shapes such as isosceles triangles, right triangles and rectangles. After getting familiarized with the basic SWNT molecular structure, students then learn the tools that are used to study these structures such as a Scanning Electron Microscope (SEM) and a Transmission Electron Microscope (TEM). With introduction of SEM and TEM students learn the concept of microscale and macroscale and how these concepts are being implemented in engineering and science. Next, students build a 3-D macroscale model of a SWNT molecule. As shown in Figure 4, they build their SWNT on a handout sheet where they are asked to find the area of one SWNT unit cell, the height of their SWNT model and the overall size ratio of their model to the actual size of a SWNT molecule.

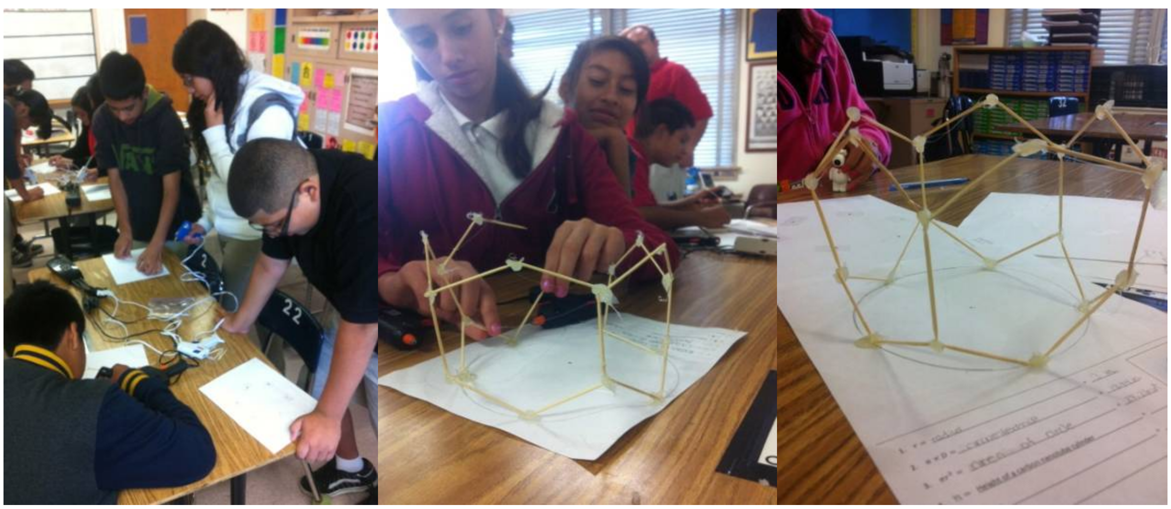

Figure 4. Investigating, building and analyzing the structure of single wall carbon nanotubes (SWNT).

Impact on Student Attitudes towards STEM

Pre and post-surveys were conducted to measure the impact of the visiting engineer/scientist and the research-related activities on students' perceptions towards engineers and scientists and their desire to pursue a career in engineering or science.

Program demographics. During the 2012-13 school year the IMPACT LA Program partnered with three middle schools in East Los Angeles and a Math and Science High School located on the Cal State LA campus (see Table 2). Seven graduate fellows, two engineers and five scientists, were partnered with seven teachers, one math, five science, and one math/science. Looking at 2012-13 graduate fellow demographics, 71% are female and 86% are underrepresented minorities. Table 3 shows the average demographics of the four partner schools along with the specific demographics of Stevenson Middle School where the activities highlighted in this paper were conducted. At Stevenson Middle School, 99% of the students are

Latino, 87% are economically disadvantaged, 33% are English Language Arts proficient (or above), and 28% are Math proficient (or above).

Table 2. Data regarding the classrooms where IMPACT LA fellows were assigned during the 2012-13 school year including the name of the partner school, the subject matter, grade level, and the topic of the fellow's research, and number of pre and post surveys collected from students in those classrooms.

Partnership School	**Subject(s)**	**Grade level**	**Fellow Research Topic**	**# of Surveys collected**	
				Pre	***Post***
Alliance Marc & Eva Stern Math and Science School	AP Biology	11-12	How Wdr68 Functions in the Craniofacial Regulatory Pathway of Zebrafish	59	46
Hollenbeck Middle School	Life Science	7	The Impact of the Introduced Eastern Fox Squirrel on the Native Western Gray Squirrel in Los Angeles and Surrounding Counties	114	98
Hollenbeck Middle School	Life Science	7	Lifetime Fitness Study	110	105
KIPP Los Angeles College Preparatory School	Physical Science	8	Spinal Cord Injury and Neuromuscular Electrical Stimulation Therapy	94	87
Stevenson Middle School	Math/ Algebra/ Geometry	6-8	Developing a Carbon Nanotube Matrix to Replace Conventional Metal Alloys	131	140
Stevenson Middle School	Math and Science	6	The Development of Microfluidic Devices for Binding and Organic Studies	61	60
Stevenson Middle School	Life Science	7	The Protection of Mitochondrial Structure and Function During a Heart Attack Using the Compound Epicatechin	143	131

Table 3. Demographics of the partner school where these activities were conducted and the average of all partner schools in the IMPACT LA NSF GK-12 Program during the 2012-13 school year. ELA refers to English Language Achievement.

Stevenson Middle School	Latino: 99% White: 1%	English learners: 24% Economically disadvantaged: 87%	ELA: 33% proficient or above Math: 28% proficient or above
Averages Among all Partner Schools	Latino 95.25% African American: 0.5% Asian Pacific Islander: 1% White: 3.25%	English learners: 20% Economically disadvantaged: 89%	ELA: 48% proficient or above Math: 41% proficient or above

Results. The graph on the left in Figure 5 shows the percentage of students that identify science and engineering as their desired major and as their desired dream job before and after the fellow worked with them in their classroom. After participating in the program, more students wanted to study science or engineering (increasing from 39.3% to 52.3%) and more students wanted to pursue a science or engineering career (increasing from 15.8% to 25.4%). The likely reason that more students wanted to study STEM than pursue a career in STEM is that many students want to pursue a career in medicine which we did not classify as a STEM career. The graph on the right in Figure 5 looks at the specific growth for science and for engineering in terms of desired college major and dream job. When asking students about what they would like to study in college, more students listed science and engineering related subjects in the post-assessment than the pre-assessment (increased by 12.9%). Furthermore, more students listed science or engineering related jobs as their dream job in the post-assessment (by 9.6%). In fact the estimated growth for dream jobs in engineering (8.3%) was greater than the estimated growth for science-related jobs (5.6%) which indicates a growing awareness of engineering as a profession.

While having more students pursue science and engineering majors and careers is an important goal, we are also interested in changing the perception of engineers and scientists. For this paper, we are particularly interested in discovering the impact the carbon nanotube research-related activities had on students' perceptions towards engineering. Attitudes towards engineering were sought by asking students to rank the statement, "I think engineeering is fun". As shown in Figure 6, comparing the pre and post-assessment results, there was a 7.7% increase on average among the other classrooms but a 12.4% increase in the classroom exposed to the carbon nanotube composite research problem. The data in Figure 6 shows that students who conducted the activities presented in this paper and who worked with an engineer in their classroom reported that they agree or strongly agree that engineering is fun.

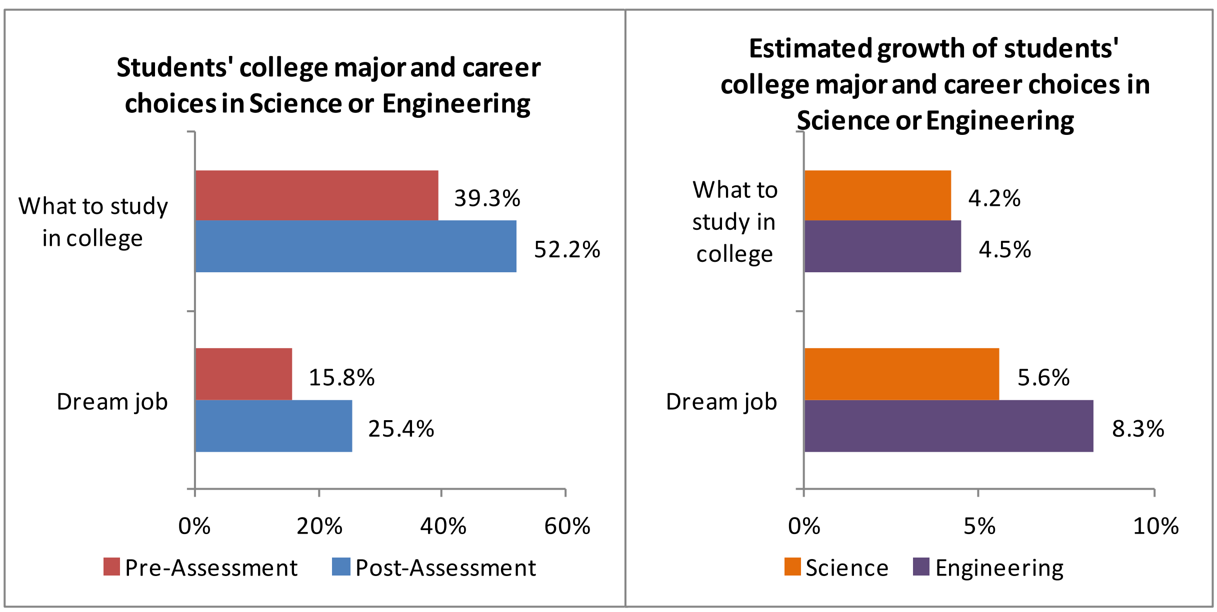

Figure 5. The graph on the left shows the percentages of students identify science and engineering as their college major and dream job before and after the fellows worked in the classroom. The graph on the right shows the estimated growth of students' college major and career choices in both science and engineering.

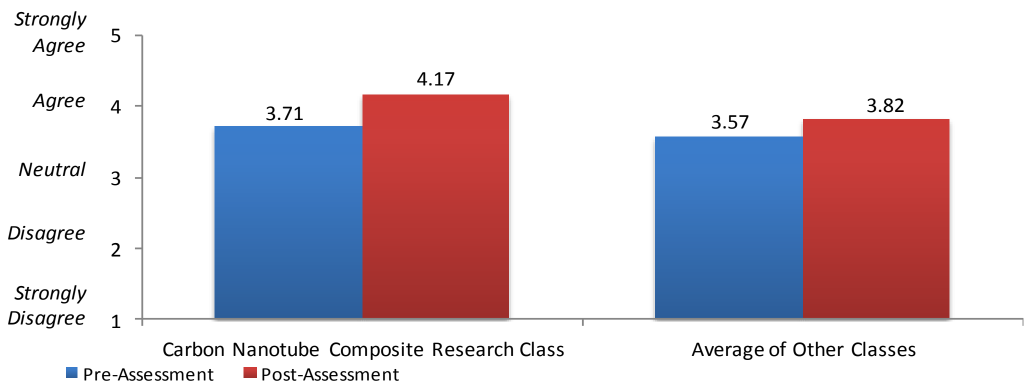

Figure 6. Survey responses to the question “I think engineering is fun.”

During the 2012-13 school year, two of the seven classes with a visiting scientist or engineering fellow were math classes. In all of the seven classes, students were asked to rank the statement “I enjoy learning math in school.” Figure 7 shows that in math classes, students sustained or even increased their interest in math whereas in the other classes, there was a decrease. There does seem to be an obvious bias towards answering this particular question more positively in a math class versus a science class as highlighted by the lower initial response in the non-math classes in the pre-assessment. Relative to their initial interest in math though, the students that were in a math class that did activities linked to authentic science and engineering research problems maintained their enjoyment of math.

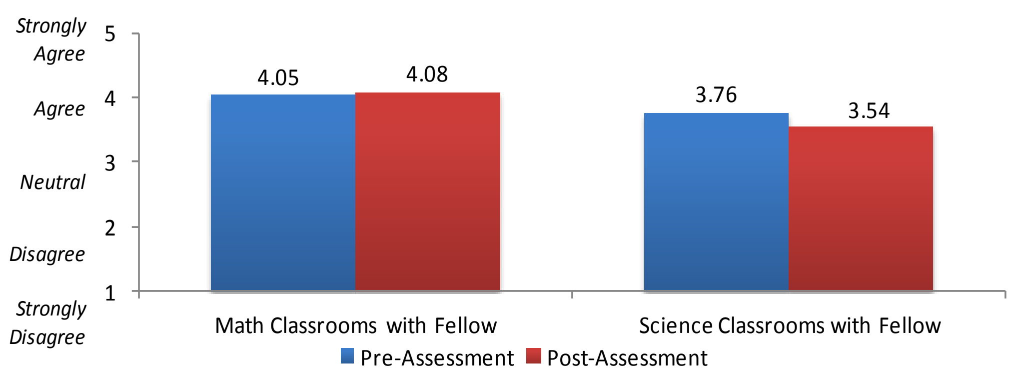

Figure 7. Survey responses to the question “I enjoy learning math in school.”

One of the goals is to increase the number of women pursuing STEM majors and STEM-related careers. Figure 8 shows the average responses by gender to the questions “I think engineering is fun” and “I think science is fun” for all classrooms with a visiting engineering/scientist fellow during the 2012-13 year. This data shows that there is a much greater awareness about what engineering is especially among girls since the growth between the pre and post-assessment for boys is 7.7% and girls is 11%. For science, the growth for boys is 7.1% and for girls is 5.9%. The larger growth for engineering is interesting since only two of the seven fellows were engineers. The larger growth for engineering is likely due to the fact that the students are not typically exposed to engineering but in our program they either had an engineer in their classroom or learned about engineering through the IMPACT LA Open House.

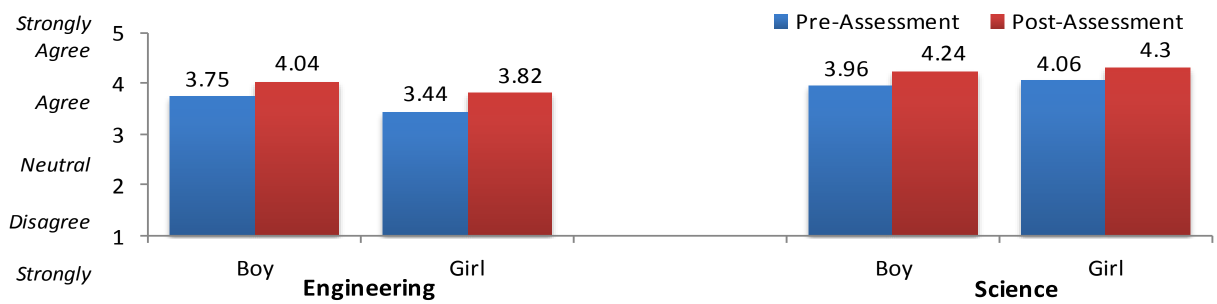

Figure 8. Survey responses by gender to the questions “I think engineering is fun” and “I think science is fun.”

To measure the impact of the IMPACT LA NSF GK-12 program on STEM literacy, we asked the students to describe “Things engineers and scientists do.” Table 4 shows that the number of students that answer “I don’t know” or that left the answer blank decreased by 8.2%. In addition, the response “Study” decreased by 10% in the post-assessment indicating that the students were more aware of the actual job of a scientists or engineer rather than simply what it takes to be an engineer or scientist. We also asked students to “List three words to describe a scientist or engineer.” As shown in Table 5, students’ perceptions of scientists and engineers improved. Students were more likely to use a positive description such as “fun/funny”, “cool”, and “awesome”. Responses such as “I don’t know”, “smart”, and “study” decreased the most. These are important results because if students have a positive perception of scientists and engineers, then even if they do not choose to study in a STEM field, they will still likely be supportive of family and friends who want to pursue STEM-related careers.

Table 4. Student pre and post responses to the question “Things engineers and scientists do”.

	Pre	Post	Difference
Experiments/ test/ research/ labs	21.6%	39.9%	***18.3%***
Life/ organism/ animals	7.8%	13%	***5.2%***
Related to fellows and their specific research	0.1%	4.2%	***4.1%***
Create/ invent something new	29.1%	30.9%	*1.8%*
Finding cures/medicine for illness/disease/bacteria	7.3%	9.1%	*1.8%*
Discover things	13.5%	10%	*-3.5%*
Build stuffs/ buildings/ houses/ structures, etc	31.0%	27.4%	*-3.6%*
Earth/ world/ nature/ environment	11.7%	7%	*-4.7%*
Fix/repair	10.3%	4.6%	***-5.7%***
I don’t know/ Blank	10.4%	2.2%	***-8.2%***
Study	27.5%	17.5%	***-10%***

Table 5. Student pre and post responses to the prompt “List three words that describe a scientist or engineer”.

	Pre	Post	Difference
Fun/ funny	7.9%	25.9%	**18%**
Cool	8%	15.7%	**7.7%**
Awesome/amazing/amusing/fascinating, etc	6.5%	9.9%	3.4%
Hard working/ hard workers/ work a lot	26.2%	28.5%	2.3%
Creative/ curious/ invent	19.2%	21.3%	2.1%
Build/ builder/ building	6%	3.6%	-2.4%

Help/ helpful/ helping	10.8%	7.5%	-3.3%
I don't know/ blank	14.9%	11.5%	-3.4%
Smart/ wise/ intelligent/ knowledgeable	70.2%	66%	**-4.2%**
Study	9.4%	4.6%	**-4.8%**

The fact that "smart" and "study" are de-emphasized in Tables 4 and 5 implies that the perceived barriers for students pursuing STEM majors and careers are lowered. This may seem an undesirable outcome to some because engineers and scientists need to be smart and study hard. But the data in Tables 4 and 5 do not necessarily imply that students do not think that engineers and scientists have to be smart and study, they instead are identifying other important attributes. To increase the number of students pursuing science and engineering careers, it is desirable for students to be more aware of what scientists and engineers do by using authentic engineering and science problems in the classroom. Furthermore it is important to have role models like the fellows with whom they can relate. In our society, people frequently interact with medical doctors, and because of that they have a good understanding of what doctors do and the impact they make on the lives of others. When deciding upon a career to study, students often do not focus on the years it takes to pursue a medical career but rather on the positive characteristics that they attribute towards doctors and medical careers. We need to be giving the same message about careers in engineering and science[11,12].

Conclusion

By exposing students to real-world engineering and science problems the IMPACT LA NSF GK-12 Program has been able to sustain their interest in math, expose them to the possibilities of careers in STEM, and increase their STEM literacy. This paper provides five activities related to research in carbon nanotubes that teachers can use in their middle school math classrooms. Furthermore, there are many other authentic engineering and science research based lessons available on the IMPACT LA website[10] for both science and math teachers.

Acknowledgments

The authors would like to acknowledge that this work was done in collaboration with the 2012-13 fellows: Patricia Sanchez, Nichole Lee, Maria Ortega, Andrea Herrera, Gregory Alvarado, Janel Ortiz; the 2012-13 partner teachers: Baron You, Christine Rosser, Cynthia Godoy John Cerezo, Laura Ruiz, and Tony Semaan; the IMPACT LA evaluation team including Simeon Slovacek and Tammy Lee; and the IMPACT LA management team: Jianyu Dong, Eun-Yung Kang, Huiping Guo, and Ethan Lipton. This work is supported by NSF Grant #0742426.

Bibliography

1. National Academy of Sciences, National Academy of Engineering, and Institute of Medicine. *Rising above the gathering storm: Energizing and employing America for a brighter economic future.* Washington, DC: The National Academies Press, 2007.
2. Gonzales, P., Williams, T., Jocelyn, L., Roey, S., Kastberg, D., and Brenwald, S. *Highlights from TIMSS 2007: Mathematics and science achievement of US fourth and eighth-grade students in an international context.* (NCES 2009-001 Revised). Washington, DC: National Center for Education Statistics, Institute of Education Sciences,U.S. Department of Education, 2008.
3. Hill, C.J., Bloom, H.S., Black, A.R., and Lipsey, M.W. Empirical benchmarks for interpreting effect sizes in research. *Child Development Perspectives*, *2*(3), 172-177, 2008.
4. National Academies Press. National Research Council. Successful K-12 STEM Education: Identifying Effective Approaches in Science, Technology, Engineering, and Mathematics. Washington, DC: The National Academies Press, 2011.

5. The Power of Partnerships: A Guide from the NSF GK-12 Program, American Association for the Advancement of Science, Washington, D.C., 2013.
6. *The NSF GK–12 program: A decade of innovations in graduate STEM training and K–12 learning.* American Association for the Advancement of Science, Washington, DC, 2011.
7. Warter-Perez, N., Dong, J., Kang, E., Guo, H., Castillo, M., Abramyan, A., & Moo-Young, K. Strengthening the K-20 engineering pipeline for underrepresented minorities. Paper presented at the meeting of the American Society for Engineering Education, Louisville, KY, 2010.
8. Alvarenga, J., Abbott, M., Abramyan, A., Dong, J., Gontar, O., Guo, H., Kang, E., Mejia, V., Pollavith, P., Sanchez, R., Zamalloa, J., and Warter-Perez, N. "Engaging Underrepresented Middle School Students in Engineering and Science through a Two-day Summer Camp," *Proceedings of 2011 American Society for Engineering Education Annual Conference*, 2011.
9. "Mathematics » Home » Mathematics." *Common Core State Standards Initiative*. N.p., n.d. Web. 31 Jan. 2014. <http://www.corestandards.org/math>.
10. "IMPACT LA NSF GK12 Program." *IMPACT LA NSF GK12 Program*. California State University, Los Angeles, n.d. Web. 31 Jan. 2014. <http://impactla.calstatela.edu/default.shtml>.
11. *Changing the Conversation: Messages for Improving Public Understanding of Engineering*. National Academy of Engineering. Washington, D.C., National Academies Press, 2008.
12. Davis, L., and Gibbin, R., at el. *Raising Public Awareness of Engineering*, Washington, D.C., The National Academies Press, 2002.