A Multitier Approach to Integrating STEM Education into a Local Elementary School

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Abstract
The targeting of elementary school students early in their education with exposure to the different Science, Technology, Engineering and Mathematics (STEM) fields will provide them future access to college offerings and career possibilities. Faculty and students from New York City College of Technology worked with young students at a local elementary school, creating and implementing programs that will help to strengthen the nation's STEM workforce and to prepare students to be productive citizens with a strong sense of self.

Introduction
The New York City College of Technology (informally known as "City Tech") partnership with P.S. 307 Daniel Hale Williams School began in 2014. The partnership aimed to promote A Better Educated City; an investment in STEM, and our nation's future. New York City College of Technology is part of the City University of New York (CUNY) system. Daniel Hale Williams is an elementary school serving students in Pre-K through Grade 5, which became a science and technology-themed magnet school for STEM Studies after being a recipient of a grant from the federal Magnet Schools Assistance Program. For the 2017-2018 academic year, 373 students

are enrolled at Daniel Hale, where 57% are male students and 43% female students. The race/ethnicity reported by the school includes a 56% Black and 27% Hispanic student population. With a similar male to female ratio of undergraduate students, City Tech reports 30% Black and 33% Hispanic (New York City College of Technology 2017). The large underrepresented population at both schools made the partnership an ideal fit. Initially, college students were hired as interns through the CUNY Service Corps program. The CUNY Service Corps organizes students and faculty across the institution to work on projects that benefit the residents and communities of New York City. These projects aim to advance the "civic, economic and environmental sustainability" of the city (City University of New York [CUNY] 2018). At the core of the Service Corps, launched in 2013 as a response to Hurricane Sandy, is civic-engagement, which aligns with the values of SENCER. Students are paid as interns to work in civic-related jobs in community organizations (CUNY 2018). During the 2014–2015 academic year, two CUNY students worked to develop and implement an Educational Outreach Program that provided students in grades 1–5 with exposure to Science, Technology, Engineering, and Mathematics (STEM) in their elementary school classrooms. To sustain the program beyond the 2014–2015 academic year, the Black Male Initiative, Emerging Scholars, and Perkins Peer Advisement programs at City Tech continued to support the outreach project. Since the program's inception, a number of City Tech undergraduate students have served as mentors to the elementary school students and have worked with faculty at City Tech and key staff at the local elementary school. The goal of this collaboration, which has spanned a number of years, was to engage college students, elementary school students, college faculty, elementary teachers, and the families of the elementary students in a STEM outreach initiative.

Why is it important to integrate STEM education into the elementary school curriculum?

Many recent studies indicate that the gap in the STEM workforce will continue to widen unless more students decide to enter the STEM fields (Brophy et al. 2008; Brown 2012; Johnson 2013). According to the U.S. Department of Commerce, STEM occupations are growing at 17%, while others are growing at 9.8% (Langdon et al. 2011). To succeed in society today, we should encourage students to solve problems, develop their capabilities in STEM, and become tomorrow's scientists, inventors, and leaders (Science Pioneers 2017). Exposure to STEM careers at the elementary school level enhances student learning, encourages creativity, and entices curiosity. The National Academy of Engineering and the National Research Council list some benefits of incorporating engineering in K–12 schools: improved achievement in mathematics and science, increased awareness of engineering, understanding and being able to do engineering design, and increased technological literacy (Katehi, Pearson, & Feder 2009). With these studies as a rationale, we developed a multitier approach to integrate STEM into a Pre-K–5 (elementary) school.

Methods

The awareness of STEM-related careers was presented to the participating staff, students and families through in-class lesson plans, afterschool programs, and family workshops. Most of the projects centered on science and civil engineering to draw from the strength of the faculty involved. The engineering design process was included in the activities. Students were encouraged to (a) identify the problem, (b) brainstorm solutions, (c) try a design, (d) test, (e) identify strengths and weaknesses, and (f) try again. In order to promote skills associated with a well-rounded scientist and engineer, the activities integrated concepts of cost, schedule, and communication. The majority of the activities (in-class lessons, afterschool program and family workshops) were held at the local elementary school. College students and faculty met and communicated regularly with the staff at the elementary school to plan all activities. We present below the project design of this multitier approach to the community.

In-class Lessons

The in-class lessons centered on the NYC Scope and Sequence for Science and the Next Generation Science Standards (NGSS). The science focus included the following two topics: The Five Dancing Spheres (biosphere, lithosphere, geosphere, cryosphere, and hydrosphere) and Weathering and Erosion. In each unit, students in

FIGURE 1:

In-class lesson plans developed by the faculty, STEM specialists, and undergraduates.

Lesson 1: What Is the Cryosphere?

LEARNING OBJECTIVES

Students will be able to:

- Define cryosphere.
- Explain how the cryosphere is an essential part of the earth system.
- List examples related to the cryosphere (ice caps, etc.).

OUTLINE

Introduction (5 min)

- Students will have time to introduce themselves and create name tags.
- Interns will introduce themselves through power point slides.

Engineering Background (10 min)

Cryosphere Lesson (15 min)

- Define cryosphere
- Show examples that can relate to the cryosphere.

Activity (cryosphere vocabulary words) (15 min)

- Students will be given pictures and asked to match them with their definitions based on their prior knowledge.
- Introduce the activity for next lesson and expand how igloos are related to structural engineering.

Homework (5 min)

- Look up a video on how to build an igloo so that they will be prepared for next class.

Lesson 2: Making an Igloo

LEARNING OBJECTIVES

Students will be able to:

- Define cryosphere.
- Explain how the cryosphere is an essential part of the earth system.
- List examples related to the cryosphere (ice caps, etc.).

OUTLINE

Introduction (10 min)

- Interns and Students will reintroduce themselves.
- Students will be shown the PowerPoint from lesson 1 to familiarize themselves with the cryosphere.
- Discuss the homework on how to build an igloo.

Activity (30 min)

- Students will be given materials to create their own igloo and shown examples of structures made of ice.
- http://www.cbsnews.com/news/a-frozen-flashy-city-arises-from-the-ice-in-china/
- https://www.youtube.com/watch?v=7OUtNkVXelk
- Leave 5 minutes so students can walk around to look at other student's creations.

Homework (10 min)

- Introduce hydrosphere and ask the students to think of examples related to its concept.

FIGURE 2:
In-class lesson plans developed by the faculty, STEM specialists, and undergraduates.

Lesson 5: What Is the Atmoshpere?

LEARNING OBJECTIVES

Students will be able to:

- Define the Atmosphere.
- Explain how the Atmosphere is an essential part of the earth system.
- List different forms of air and relate it to the Atmosphere (wind, storm, hurricane, etc.).

OUTLINE

Introduction (5 min)

- Students will be asked to give some examples of the Atmosphere.

Atmosphere Lesson (25 min)

- Define Atmosphere and give some examples.
- Introduce the different layers of the atmosphere and their properties.
- Show how Atmosphere in the form of wind has helped human beings since the dawn of civilization as a source of renewal energy.
- https://www.youtube.com/watch?v=niZ_cvu9Fts

Activity (atmosphere vocabulary words) (15 min)

- Students will be given pictures and asked to match them with their definitions based on their prior knowledge.
- Introduce the activity for next lesson and summarize how engineers use Atmosphere to generate green energy.

Homework (5 min)

- Introduce students about wind turbine and how to make their own using paper and a ruler.

Lesson 6: Making a Wind Turbine.

LEARNING OBJECTIVES

Students will be able to:

- Define the Atmosphere.
- Explain how the Atmosphere is an essential part of the earth system.
- List different forms of air and relate it to the Atmosphere (wind, storm, hurricane, etc.).

OUTLINE

Introduction (15 min)

- Students will be shown the PowerPoint from lesson 5 to familiarize themselves with the Atmosphere.
- Students will share with their group members and the class the materials they have for the activity.

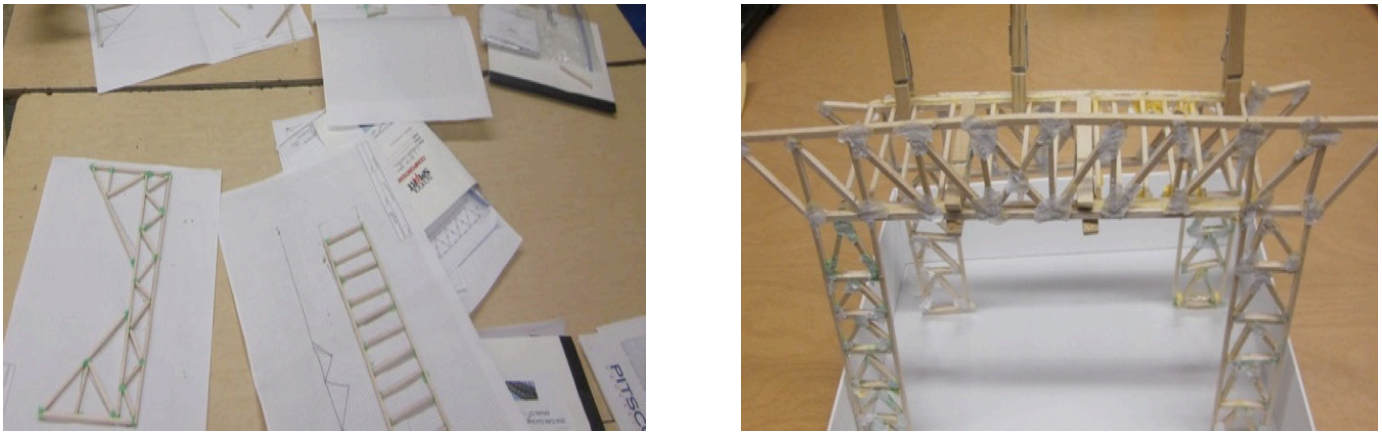
Activity (30 min)

- Students will use the materials supplied to them to make a wind turbine. Any ideas students come up with will be included into the project.

Homework (5 min)

- Introduce Biosphere and ask the students to think of examples related to its concept.

FIGURE 3 represents balsa wood bridges/replicas being built from sketches.



grades 3 and 4 explored these science fields and created models to represent and display their learning. The civil engineering focus included the following in-class lesson topics: What is Engineering, Types of Engineering, Structures and Functions, Teams behind Construction, Construction Drawings, and Sustainability. The goal of the in-class lessons was to enhance the existing science curriculum with real-world applications and hands-on projects to help the students better understand the science curriculum. The commitment and participation of teachers from the elementary school were critical to the success of the program. The teachers and undergraduate students met regularly to plan, reflect, and ensure a smooth link between the NGSS curriculum and the in-class lesson topics. The teachers provided insight on teaching techniques for elementary school-age children and diverse learning styles. The undergraduate students worked closely with the teachers and tailored their lessons and activities to the children in the classroom.

The lesson plans for The Five Dancing Spheres curriculum (Figures 1 and 2) at the elementary school is only one example of the approach that we implemented. Each lesson included a visual aspect (examples), vocabulary activity, homework, and a hands-on activity.

Afterschool Programs

The afterschool programs reflected the model used in two local design competitions: West Point Bridge Design and Future City. These competitions are aimed at middle school students to promote interest in civil engineering careers. These projects required students to model the Engineering Design Process. Students used software programs to design their projects, create physical models, and prepare oral presentations. Even though students did not participate in the competitions, they were encouraged to be problem solvers and engineers. Students were encouraged to design, test, and revise their ideas. This provided a great opportunity for students to use their math, science, and technology skills while working with the engineering design process to come up with various solutions.

Engineering concepts such as force and equilibrium were incorporated through the Bridge Design project. Students used the Bridge Design software to design their bridges and simulate the testing of the bridge. Bridge Designer is a zero-cost educational software intended to provide middle school and high school students with a real-world overview of engineering through the design of a steel highway bridge (Ressler 2013). These elementary students were introduced to concepts of tensile and compressive force. Students created a virtual bridge and a replica model of their virtual bridge using balsa wood (Figure 3). Each material had a cost assigned to it, and students worked to make the strongest and most affordable bridge.

Similarly, concepts such as city planning and sustainable design were taught through the city design project. Future City is a project-based learning program where students in 6th, 7th, and 8th grade imagine, research, design, and build cities of the future (National Engineers Week Future City Competition 2017). Our afterschool partnership brought this project to the elementary students at P.S. 307, and they successfully created their own virtual city using the Sim City software. Students made blueprints of their cities and created a replica model showing a block of their cities using all recyclable materials. In preparing a blueprint, students visualize and sketch their design. Transferring the design from paper to three dimensions helped the students make a connection from 2-D to 3-D, promoting spatial thinking. Spatial thinking has been identified as an important trait for STEM careers (Wai, Lubinski, & Benbow 2009). "Fostering spatial thinking and mathematics learning in elementary school could contribute to a downstream ripple effect, improving students' interest and success in STEM subjects throughout their education and into their careers" (Burte et al. 2017).

The process of calculating total cost introduced the idea of budgets and the importance of adhering to a budget. Students also had to adhere to a schedule, as they were limited in the amount of time they could work on each portion of the project. Students presented their projects at the end of each program.

Family STEM Workshops

Recognizing the importance of family involvement in a child's success, the program included interactive STEM workshops and field trips for families that increased their awareness of STEM-related careers. Survey and program assessment data informed planning for the next project year. Topics in the family STEM workshops included, but were not limited to Civil Engineering, Chemistry, Mechanical Engineering, Architectural Engineering, and Computer Systems Technology. One local field trip included the SONY Wonder Technology Lab in New York City.

Some of the activities that were introduced at the workshops were (a) Spooky Materials Testing experiment which included a Mechanical Engineering focus; (b) building a home for turkeys with a Civil Engineering focus; (c) dissolving M&Ms and making slime with Chemistry; (d) learning coding with puzzles with a Computer Engineering focus; and (e) the design and creation of an architectural building model with Architectural Engineering as the focus.

The Spooky Materials Testing experiment (Schooling a Monkey 2018) introduced stress concepts to the elementary students by applying the different types of stresses (tensile, compressive, shear) to different types of candy and comparing the results of the tests on each candy. Students then made connections as to which type of candy, based on the stress concept, would be best for building.

Building a home for a turkey (Preschool STEAM n.d.) introduced the structural concepts and material cost to the students. The goal was to contain the holiday turkeys in a structurally sound and cost-efficient space. There were time limits and cost constraints that the students had to comply with. Students were also given a range of materials, each with a certain cost assigned.

Dissolving M&Ms (American Chemical Society 2018) and making slime (STEAM Powered Family 2018) introduced the concept of chemical experimentation and observation. In both activities, students were able to combine substances and observe the outcomes, which were colorful, fun, and thought provoking. With the help of parents, the students poured rubbing alcohol, water, and oil onto a plate of M&Ms and saw the dissolving effects the different solutions had on the M&Ms. The slime-making activity reinforced the concept of how observations are important in chemical processes.

Learning coding with puzzles introduced the algorithmic concept of coding patterns to the students (Institute of Electrical and Electronics Engineers 2018). This was accomplished through a brief introduction of how to follow steps using "coding language" and a visual puzzle activity that involved critical thinking. The students were then encouraged to "walk out" their coded steps on a large grid that closely followed the worksheet they worked on. As a next step, students and their families applied the skills they had learned to the online software in code.org.

By designing and creating an architectural building model, students were able to see the problem-solving and aesthetic skills it takes to become an architect. Students were given a laser-cut bendable paper set to create 3D models of their structure. Each student received the same pieces, but each individual was able to create entirely different structures by arranging the structure to their liking.

Results and Discussion

The faculty at New York City College of Technology recruited undergraduate students enrolled in the departments of Biological Sciences, Chemistry, and Civil Engineering Technology to serve as mentors, which included a pool of about 750 students. Throughout the years, several programs have provided support to the college students involved in this endeavor. These included the CUNY Service Corps, Emerging Scholars, Perkins Peer Advisement, and the Black Male Initiative programs, all of which have recognized the value of the STEM Outreach program. The success of the partnership and the collaboration of college faculty and students at City Tech has opened the eyes, minds, and future career potential of the elementary students at P.S. 307 Daniel Hale Williams School. It reinforced the need for STEM education in underrepresented learners. The partnership has increased exposure at the elementary school to STEM topics and courses taught at the college level. The outcomes as shown have been favorable and shared with the community at large via showcase presentations, school displays, and conference presentations, and at the college's annual poster session.

Success(es)

Our success included presenting activities seen as academically challenging (geared only to junior high, high school, or college students) to the elementary school students at P.S. 307, in a way that led to both success and enjoyment for the students. Furthermore, these students were able to figure out what STEM topics they enjoyed by trying many different discipline-oriented workshops. By including the parents in our workshops, we were able to inform them about various fields of engineering, next step school options for their elementary child, and career opportunities. Elementary school students were able to successfully implement the information they were learning through interactive hands-on STEM activities.

Impact on Undergraduate Students

There is a large body of evidence of the positive impact of undergraduate research on college students (Lopatto 2010; Russell, Hancock, & McCullough 2007). George Kuh (2008) also points to high-impact practices such as engagement beyond classroom (internships) and community-based learning that promote student engagement. The STEM outreach that we have described demonstrates that working with community partners such as the elementary school represents a valuable community-based project. The CUNY Service Corps indicate that undergraduates gain "workplace skills and abilities; personal development; civic engagement and social issues awareness" (CUNY 2017). The undergraduate students developed the curriculum under the guidance of the faculty and elementary school teachers. Additionally, the students gained valuable experience for the real world, including organization and communication and presentation skills.

Conclusion

This work brings to the forefront a collaboration that engaged faculty, undergraduates and elementary school students and teachers in a STEM outreach project. The project, which aimed to promote A Better Educated City, has increased awareness of STEM careers among families at the elementary school. Students were engaged in hands-on activities while learning elementary concepts related to STEM. Exposing elementary school students to science and engineering concepts can motivate them to solve various problems more effectively. "Quality STEM education is vital for the future success of students. Integrated STEM education is one way to make learning more connected and relevant for students" (Stohlmann, Moore, & Roehrig 2012, 28). Engineering is traditionally not a subject that is taught in elementary schools. However, it is a powerful method of teaching and motivating students in STEM-related fields. "Research indicates that using an interdisciplinary or integrated curriculum provides opportunities for more relevant, less fragmented, and more stimulating experiences for learners" (Furner & Kumar 2007, 186). Adding science, and more importantly, engineering as a part of the elementary school curriculum can be an effective way for students to strengthen their science, mathematics, and technological skills.

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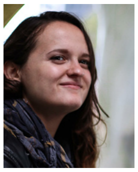

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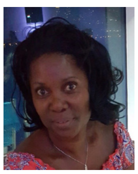

Servena Narine is a licensed and certified NYC Board of Education teacher. She currently works at Daniel Hale Williams Public School 307 Magnet School for STEM Studies. She has been an educator at P.S. 307 for 22 years. Over the course of her career, she has served as a classroom teacher (Grades Pre-K, 1, 2 and 3), mathematics coach, technology teacher, magnet resource specialist, and mentor. No matter the position, role or duties, she enjoys each, in addition to working with staff, students, parents, and partnerships. She brings to her work a focused and organized structure which has benefited her and the school over the years.

Melanie Villatoro is an assistant professor in the Department of Construction Management and Civil Engineering Technology. She teaches a variety of courses in the civil engineering major including statics, strength of materials, concrete, steel, soil mechanics, and foundations. Prof. Villatoro's approach to teaching builds on developing rapport with her students. She is highly effective in the classroom and as an advisor and mentor. She is passionate about student retention and performance, as well as STEM Outreach from the elementary to the high school level.

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