

Fundamental: A Teacher Professional Development Program in Engineering Research with Entrepreneurship and Industry Experiences

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1. Introduction

Recently the U.S. has dropped out of the top-10 list for innovation ranking, primarily due to our lack of focus on educating the citizenry in STEM disciplines [1]. To ensure the U.S. competitiveness in the 21st century innovation economy, there is a need to develop a scientifically and technologically trained workforce [2-4], which necessitates the design and implementation of novel curricula, methodologies, and paradigms for STEM education. Rapid acceleration in the development of robotics, artificial intelligence, and autonomous driving technologies have led to forecasts about the changing nature of the future of work. Such rising expectations for the 21st century workforce demand that our K-12 schools and universities devise and implement novel curricula, methods, and paradigms for STEM education to serve as the bedrock of the innovation economy.

The recently released *Next Generation Science Standards (NGSS)* [5] explicitly integrate engineering design in K-12 science standards and draw connections to the *Common Core State Standards for Math (CCSSM)* [6]. The NGSS [5] utilizes a 3D learning model that includes Science and Engineering Practices (SEPs), Disciplinary Core Ideas (DCIs), and Crosscutting Concepts (CCs). The SEPs are integral in engineering education because they not only support teachers and K-12 students to develop an understanding of what scientists and engineers do but also promote hands-on lessons that include open inquiry, which is the hallmark of scientific research.

Unfortunately, even as today's students effortlessly interact with modern technological artifacts, they often lack an understanding of the underlying engineering, technology, and business processes. As technology continues to permeate and impact all aspects of our daily lives, it is essential that all students receive comprehensive, quality STEM education from adequately trained teachers. Teachers must be prepared to provide their students not only the STEM content knowledge but also the motivation and self-perception to join the STEM workforce. Unfortunately, many teachers are often perceived to have less experience with technology than the students they teach [7,8]. A technology-driven transformation of the entrepreneurial landscape is paramount to the creation of new sustainable jobs and the growth of the U.S. economy [9]. This necessitates the reversal of the perennial disinterest in STEM disciplines among college-bound students through compelling education and training opportunities that attract, retain, educate, and graduate a large number of qualified and informed entrepreneur-engineers who can create novel products and businesses for the innovation economy.

To facilitate the improvement of interest in STEM related disciplines, faculty, graduate researchers, and undergraduate students of the NYU Tandon School of Engineering (NYU SoE) have collaborated with K-12 teachers for over 15 years to (i) allow them to experience SEPs through engagement in real-world engineering research and (ii) help build-up their capacity for implementing real-world, high quality lessons and activities within STEM disciplines. Building on these past experiences, in 2017 summer, our project team hosted nine teachers for a six-week long summer professional development (PD), beginning with a two-week hands-on, structured learning followed by a four-week collaborative engineering research and periodic industry interaction experiences. All teachers came from New York City schools to attend the full-time (five days a week for eight hours each day) PD program. This paper describes activities and outcomes of this teacher PD program, which allowed participants to have authentic experiences in engineering, technology, entrepreneurship, and industry. Detailed overview of PD curriculum, activities, research projects, and teacher outcomes (e.g., technical quiz, self-perception, and external evaluation) are provided.

2. Program Rationale Supported by Literature Review

In order to address the SEPs in NGSS, this teacher PD program incorporates the following components: learning about robotics and mechatronics; immersion in hands-on, collaborative research; opportunities to foster entrepreneurial skills; and interactions with engineers from industry. The key elements of our PD program are as follows.

1. Introduce the multidisciplinary fields of mechatronics and robotics to teachers using a structured and integrated learning environment, consisting of training, mentoring, and real-world collaborative engineering research, to renew their science, math, and research skills.
2. Provide teachers with experience, skills, and resources in hands-on, engineering research, prototype product development, entrepreneurship, and professional engineering practices so that they can: integrate project-based learning (PBL) in their science and math curriculum; enhance school labs with technology used by scientists and engineers; improve their communication, presentation, and business skills; and inspire their students, through examples of real-world applications, to pursue careers in STEM and create technology ventures.
3. Assess program activities and disseminate outcomes.

As elaborated below, PBL, engineering research, and entrepreneurship and industry experiences are purposefully integrated in this PD program so that educators can link classroom teaching and learning in STEM disciplines with real-world STEM practices.

To develop a technically literate workforce, educators must not only teach STEM knowledge but also address students' question: "Why do I need to know this?" Engagement of industry in PD can allow teachers to inform students about job opportunities based on their own experiences. Such a

strategy can support students to form professional identities and motivate them to pursue STEM-related careers. PBL curriculum incorporating mechatronics, robotics, and entrepreneurship is expected to further enable teachers to address this challenge as they will be engaging students in investigating authentic problems. Science and math teachers have been shown to be most effective when they possess a conceptual understanding of disciplinary fundamentals, have solid curricular content knowledge, and are fluent in pedagogical content knowledge [10-12]. One teacher-education society recommends [13] that teachers be prepared to facilitate learning by grounding STEM concepts in tangible human problems and their larger contexts. This program has been designed to provide such PD to prepare teachers to use mechatronics, robotics, and entrepreneurship to connect science and math with students' contemporary interests. Effective STEM PD supports transfer of training by immersing participants in content knowledge, allows modeling and practice of desired skills, promotes collaboration, and lasts for sufficient duration to handle the cognitive demands of new learning [14-18]. These research-based practices of effective PD have been adopted and embedded in a PLC [19], which, as a combination, has been shown to engage teachers in applying PD effectively to the classroom.

PBL can be effectively explored using the exciting fields of mechatronics (synergistic integration of mechanical engineering, control theory, computer science, and electronics to manage complexity, uncertainty, and communication in engineering systems [20,21]) and robotics (synergistic integration of mechanical structures, mechanisms, electromechanical components, microcontrollers, and programming [22,23]), which can spark the intellectual curiosity of PD program participants and engage their interest in hands-on STEM learning, engineering research, and entrepreneurial explorations. This disciplinary theme is selected for several reasons. First, these disciplines are well suited to PBL [24-26], in which participants learn both content and thinking strategy through facilitated problem-solving contextualized in a design project [24,25], which entails more than one solution [27]. By promoting knowledge synthesis from multiple domains [26], PBL can foster participants' higher-order cognitive skills [28]. Second, many STEM principles are inherently incorporated into creating mechatronics devices or performing simple tasks with robots. Mechatronics and robotics activities can afford participants opportunities to visualize and practice STEM concepts that they otherwise find difficult to comprehend while learning and experiencing tools used by STEM practitioners [28-30]. Third, we believe that mechatronics and robotics offer an ideal technology platform to build entrepreneurial ventures. For example, robotics is still a developing technology and innovations that address niche problems have the potential to develop into successful businesses. The decreasing cost of electronics and hardware components along with technological advancements in additive manufacturing promise to significantly lower the cost of robot hardware, making the use of robots economical in diverse industries [31]. Mechatronics and robotics designs can provide participants with a comprehensive experience in systems integration and product development through which they can practice and hone their skills in creativity, inventiveness, and entrepreneurship and gain an appreciation of the pathway from STEM education to careers.

In regards to career opportunities, research contrasting the outcomes of internship experiences of students *vis-à-vis* their non-intern counterparts reveals that interns often (i) have a higher GPA [32,33]; (ii) graduate earlier or at a younger age [32,33]; and (iii) receive better employment opportunities [33-35]. These findings can be linked to diverse experiences and benefits accrued from formal and informal learning occurring in a work-based environment, e.g., expertise and knowledge gained from practitioners [36], familiarization with the modern industry practices, and insight into knowledge and skills. These experiences, knowledge, skills, and benefits transcend the academic environment and are fostered and rewarded in industry. The internship model confirms that the social practice of a skill promotes learning [37]. In this spirit, promoting teachers' interactions with professional engineers through industry site-visits and mentoring can, as further evidenced in this work, enhance their practical knowledge of STEM disciplines. Following the industry experience, teachers can impart the observed and gained skills and practices to students through the modeling of cognitive apprenticeship [38], thus improving students' understanding of STEM curriculum as well as the awareness of engineering workplace.

The project activities in the program support and address city [39,40] and statewide performance standards [41], national benchmarks [5,6,42-44] for science and math, and the technology foundation standards [45]. The project also explicitly aligns with the NGSS framework with which teachers require ongoing support to effectively teach science. Specifically, the following disciplines were impacted, physics (units in: mechanics, energy, electricity, optics, magnetism, waves, motion, internal energy, etc.) and math (units in: numbers, numerations, operations, modeling, measurement, patterns, and functions). For details on these units see [5,6,39-44]. Moreover, the project activities satisfy Standard 5 in the State Learning Standards in Mathematics, Science, and Technology [46]. Specifically, Standard 5 fosters technological literacy by requiring students "to apply technical knowledge and skills to design, construct, use, and evaluate products and systems." Following skills outlined in Standard 5 are targeted: (i) modeling and optimization for engineering design; (ii) facility with selection and use of technological tools, materials, and processes; (iii) ability to use the computer as an engineering design and information processing tool; (iv) understanding of systems engineering principles; and (v) management of technology to develop competent products and processes. Project activities provide teachers hands-on experience in real-world applications of mechatronics technology, such as mobile robotics, which is often cited as an exciting and motivational teaching tool for the K-12 environment [47,48].

3. Program Overview

Under the Research Experience for Teachers (RET) Site program of the U.S. National Science Foundation, NYU SoE offers a paid research internship for 10 to 12 teachers each summer. Teachers are provided with intensive PD in STEM disciplines and an opportunity to participate in engineering research projects in collaboration with graduate, undergraduate, and high school

researchers under the leadership and mentoring of faculty researchers. The project team invites STEM teachers from over 400 local middle and high schools to apply for the research internship project. Along with extensive advertisements at science fairs and robotics competitions, the team organizes several open house sessions allowing teachers to visit NYU SoE and better understand the project's requirements, opportunities, commitment, follow-up, etc. Each year, between 10 to 12 teachers are selected from over 30 applications by a selection committee comprising of faculty and experienced graduate students. The selection is done based on evaluating the application materials consisting of a cover letter, formal application approval by the school principal, scholastic record, personal essay, recommendation letters, vita, etc. Post-selection, the finalists meet the project personnel to plan and prepare for the summer program and accommodate teacher-mentor matching. For the 2017 summer PD program originally 10 teachers were selected of whom one teacher discontinued participation after two days due to personal scheduling conflicts.

3.1. *Introductory phase:* The summer PD program began by providing teachers a welcome orientation to NYU SoE and socializing with the faculty and engineering researchers. The welcome orientation was followed by lab tours, introduction to the participating research personnel, and a lab safety session. The teachers were provided with an overview of the program and presented illustrative examples of research projects performed by participants from prior years. Additionally, a research kit consisting of components, supplies, and study material was distributed to the teachers for their use throughout the summer and eventually for use in their schools.

3.2. *Guided training phase:* The next two weeks of the summer PD program involved 20 guided training sessions conducted under the supervision of faculty and a doctoral student. The training sessions provided teachers detailed introduction to fundamentals of sensors, actuators, electronics, electro-mechanical components, microcontrollers, robotics, and entrepreneurship. Each day contained a morning and an afternoon session with each session comprising of one-hour lecture followed by two-hours of hands-on experiments. The hands-on experiments provided teachers with a better understanding and illustrated real-world applications of the concepts discussed in the preceding lectures. Each day ended with a discussion among the teachers summarizing the day's lessons, remarks, and ideas for integrating these activities to illustrate science and math concepts in their classrooms. These discussions allowed teachers to envision how to transfer their new learning to their schools and classrooms. Guided training sessions on entrepreneurship provided teachers a unique opportunity to develop their innovation, entrepreneurship, venture creation, and networking skills as well as to gain a real-world understanding of engineering workplace and careers. Key concepts included assessment of business opportunities; strategies for managing financial, human, and technology resources; networking; business promotion; and sustainable growth. Teachers participated in group activities and examined business models of successful companies that started as small entrepreneurial ventures. Table 1 shows various topics discussed in the guided training sessions. See Figure 1(a) showing participants engaged in a guided learning activity.

Table 1: Guided training topics

Day	Session	Topic	Day	Session	Topic
1	AM	Introduction	2	AM	Mechatronics
	PM	Resistors and capacitors		PM	LEDs
3	AM	Push buttons	4	AM	Optoelectronics
	PM	Transistors		PM	Motors
5	AM	555 Timer	6	AM	Temperature sensors
	PM	Analog to digital convertor		PM	Robotics
7	AM	Infrared sensors	8	AM	RC filters
	PM	Relays		PM	Operational amplifiers
9	AM	Entrepreneurship	10	AM	Entrepreneurship
	PM				



(a)



(b)

Figure 1: (a) PD participants conducting hands-on learning activities during guided training and (b) PD participants discussing research projects

3.3. Research and industry interaction phase: During the four-week collaborative research phase, to experience the process and challenge of conducting authentic engineering research, teachers worked individually or in teams to collaborate with and contribute to ongoing projects (discussed in Section 4) involving graduate, undergraduate, and high school researchers, and faculty members. The research collaborations allowed teachers to practice and implement the skills acquired during the guided training sessions and experience the process of conducting research in a professional research environment while practicing their communication, research, and teamwork skills. Section 4 provides detailed information regarding the significant contributions made by the teachers during the four-week collaborative research phase. See Figure 1(b) showing participants discussing research projects.

Additionally, talks from industry professionals, including a two-day robotics workshop by an industry partner, along with visits to startup and industry sites provided ample industry exposure to the teachers. Specifically, during the four-week research phase, periodic visits to and from

industry professionals, and talks from and interactions with them, afforded teachers insight into the functioning of industry and correlate industrial practices with theory. Industrial visits included trips to and from: (i) a startup company (VirtualAPT Corp., see Figure 2(a)) that uses mobile robots with 360° camera to map high-end residential and commercial real-estate and integrate the map into a virtual-reality application for marketing; (ii) a medical research facility (Motor Recovery Research Lab, Rusk Rehabilitation Center at the NYU Langone Medical Center) that conducts cutting-edge research on rehabilitation and recovery; (iii) a robotics research and development company (Honeybee Robotics) that performs innovative and collaborative engineering projects for federal agencies such as NASA, U.S. Dept. of Defense, etc.; and (iv) a technology consulting company (Vkanix, Inc.) started by a graduate of NYU SoE. These experiences enabled teachers to connect real-world applications with concepts learned in the guided training phase and research lab. A two-day hands-on robotics workshop was conducted by an industry partner, Parallax, Inc. Teachers were provided with robotics kits and lessons to construct a robot and control it using a Blockly-based visual programming interface. Sensors, actuators, microcontrollers, and programming logic were few of the many concepts explored during the workshop. See Figure 2(b).



(a)



(b)

Figure 2: (a) PD participants visiting a start-up company and (b) PD participants attending a two-day robotics workshop

4. Illustrative Research Projects

4.1. Vertically driven inverted pendulum: To better understand, simulate, and optimize the walking of a biped robot, Mr. G.W. (all teachers are cited by their first and last initials) modeled and constructed an inverted pendulum. By studying the inverted pendulum in an unstable equilibrium (upright position), he investigated methods of stabilizing the pendulum. He built a 3D-printed inverted double-pendulum (see Figure 3) and connected it to an electric motor. He actuated the pendulum at frequencies higher than its natural frequency to achieve and demonstrate stability in an upright position. He examined data based on Mathieu's equation and concluded that the stability of the designed pendulum was reasonably close to theoretically predicted data.

4.2. Measuring mechanical forces exerted by cells: In this effort, Ms. S.G. focused on creating a fabrication process for polydimethylsiloxane stamp (PDMS) and a prototype for the

microfabricated post-array detectors (MPADS) using a microfabrication technique. The PDMS can be used as a single cell capture device and the MPADS as cellular force measurement sensors. She constructed the PDM molds to visualize the cells and to be later used as MPADS. After photographing the cells (see Figure 4), she used a MATLAB software package to analyze the traction forces exerted by the cells. She also investigated how each post can be readjusted in the center of the new grid, correcting distortions caused by cells. She formulated this research based on the hypothesis that the force can be measured indirectly by equating it to the deflection of the micro-posts using the beam bending theory. In collaboration with her partner graduate student, she calculated force from displacement of the tip of the posts on the MPAD using spring theory concept and force-displacement proportionality relationship.

4.3. Fish-bots to conduct controlled experiments on fish behavior: Mr. C.L. and Ms. D.K. worked as a team to design and build a wirelessly controlled robotic-fish (see Figure 5) for use in studies of fish/marine environments, and to inspire K-12 students to study robotics. Their system contained a smartphone application to control the movement of the fish, a router that facilitated wireless communication, an Arduino Uno with an Ethernet shield, and an RF communication system. They connected a radio transmitter to the Arduino to send signals to a radio receiver inside the robotic fish. They developed and implemented a software package containing the Arduino code for radio communication with the robot and Wi-Fi communication with the smartphone. The current version of the Fish App was developed for iPhone.

4.4. Analysis of rapid manufacturing of a microfluidic device: The need for large-scale analysis of cancer cells and the chemicals they release is imperative for understanding the way in which they propagate. Usually, this involves microfluidic technology and lab-on-a-chip to maximize analysis with PDMS. Standard microfluidic device manufacturing methods using PDMS utilize soft lithography, but they require a cleanroom and special equipment. Mr. S.C. focused on a project to determine how MakerSpaces can allow microfluidic devices to be prototyped and tested using simpler, cheaper, and less time-consuming methods than soft lithography, such as laser etching of acrylic and male-female molding. Following many failed attempts, he successfully prototyped a microfluidic device (see Figure 6) after experimenting with multiple iterations of molding methods and chemical combinations for an optimal technique.

4.5. Localization of multi-robot systems: Mr. D.M. and Mr. M.M. collaborated on the development of a software package based on the Robot Operating System (ROS) to facilitate seamless communication and transfer of location information between robots. To effectively setup a distributed network (see Figure 7) and enable information transfer between the robots, they had to understand the concept of custom messages in ROS. Later, using fiducial marker-based tracking, they extracted localization information and constructed a custom message that is transferred to peer robots. The project further involved reflecting the localization information of the robots into an iPad app for user interaction.

4.6. Game-based tele-rehabilitative solutions for stroke patients: The goal of Mr. A.R. in this project was to iterate through the design cycle, focusing on both hardware and software, to create better solutions for healthcare. He researched hardware components to measure some form/function of the body requiring training. Moreover, he investigated software components to enable interactive visualization of real-time data of body form/function, much like a video game for encouraging users to make progress in their training. After conducting research on conditions, such as heart disease and stroke, and examining the treatments, i.e. exercises, he picked one measurement that can be used to assess the patient's progress with an exercise and determine which sensor(s) could appropriately measure it. Next, he developed a hardware prototype (see Figure 8) and addressed data visualization using software of participants' choice (Processing, Unity, etc.), and integrated the entire solution with a gaming environment.

4.7. Constructing an actuated passive walker: Locating the region of balance stability is a major concern in studying the dynamics of different bipedal robots. One type of a bipedal robots is a passive walker that relies on changes in gravitational potential energy to propel itself in a dynamically balanced gait, a continuous state of falling, catching, and then righting itself. Unlike other bipedal robots, passive walkers are the most accessible for studying the complexities of the gait cycle, as they exhibit both under-actuated degrees of freedom and dynamic stability with the simplest possible design. In this study, based on an open-source actuated passive walker, Rando [49,50], and using open source hardware and software, Ms. D.R. created an actuated passive walker (see Figure 9). She carefully analyzed and constructed the robot after making multiple design improvements to yield a lightweight frame with even weight distribution.

5. Lesson Plans Development

During the summer PD program, teachers also designed lesson plans for classroom use based on the experience gained from the guided training and research phases. Lessons were carefully tailored for middle/high school students to encourage and enhance their participation in STEM activities. Below are descriptions of three sample lessons. Other lesson plans were developed to explore computer programming, computer-aided design (CAD), prototyping, etc.

Lesson 1: "Filtering frequencies of light using MATLAB" was founded upon the research experience of Ms. S.G. on the research project "Measuring mechanical forces exerted by cells" (see subsection 4.2). In this lesson, students will use MATLAB to filter colors of an RGB image and compare how green leaves of plant filter out different wavelength of light in the spectrum using chlorophylls during photosynthesis.

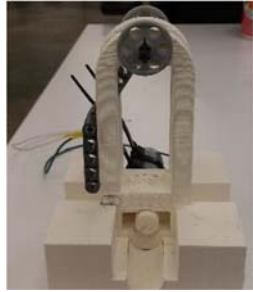


Figure 3: Double inverted pendulum

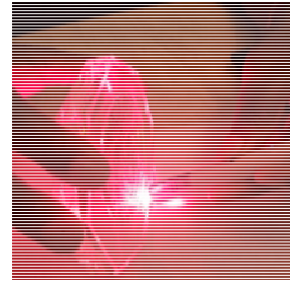


Figure 4: MPADS force measurement



Figure 5: Robotic fish

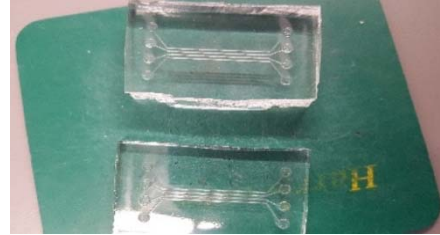


Figure 6: Microfluidic device manufacturing

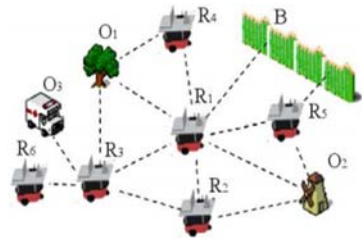


Figure 7: Localization of multi-robot systems

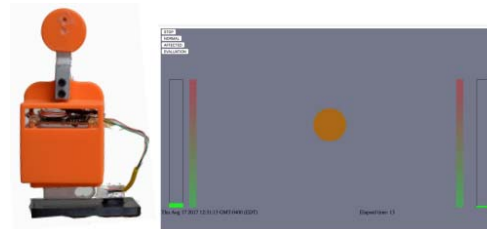


Figure 8: Game-based rehabilitation solution



Figure 9: Actuated passive walker

Lesson 2: “Physical computation therapy” was a lesson inspired by the research of Mr. A.R. on “Stroke-based tele-rehabilitative solutions,” (see subsection 4.6). In this lesson, students will select a condition such as heart disease, stroke, etc., and examine the treatments, i.e., exercises, that exist for it. Then they will choose at least one measurement that can be used to assess the patient’s progress with an exercise and determine which sensor(s) can appropriately measure it. Once a hardware prototype is developed, students will visualize the data using a software of their choice (Processing, Unity, etc.).

Lesson 3: In “Constructing an actuated-passive walker” lesson by Ms. D.R., students will be presented with a semester-long “Maker challenge” (see subsection 4.7) asking them to design and engineer a walking robot. They will work in groups to provide drawings and descriptions of their designs and explore possible refinements based on scientific concepts, group discussion, and teacher input.

6. Evaluation Results for the Summer PD Program

This section highlights the results of project evaluation that was performed by an external evaluator (Dr. L.G.) based on the following activities.

1. Surveys to gather data about the participants’ pre/post familiarity with mechatronics concepts and skills.
2. Pre/post-program surveys looking more generally at the teachers’ approaches in the educational process and their experiences during the program.
3. A site visit that included discussions with the participating teachers and visits to their research labs.
4. On-site discussions with the program director (lead faculty researcher) and graduate research assistant (lead graduate researcher).
5. Data analysis and report preparation.

The nine participants reported teaching Chemistry (3), Living Environment (2), Physics (2), Computer Science (3), Math (3), and Engineering. Three of the participants had previously participated in summer research internship programs for teachers (e.g., RET). The other six said they had previously engaged in scientific or educational research of some kind. They reported an average of 10 years teaching experience. The first rated item, on a five-point scale, for the program pre- and post-surveys asked participants to indicate the level of priority for a number of areas in their teaching. The purpose of this item was to consider the teachers’ interests and concerns. Ratings were high for most items on both the pre-and post-surveys. The average of the means increased by 0.65 from the pre-to the post surveys (3.81 and 4.46). Results indicate that teachers placed particularly high priorities on: students learning basic information; teaching problem solving; encouraging cooperative work; and improving communications skills. Substantial

pre/post increases were found in: including business-related skills, including research skills, encouraging STEM-related careers, and technological innovation. These areas are related to the PD program goals and activities.

The evaluator also used a 35-item survey to assess teachers' familiarity with mechatronics skills, concepts, and devices introduced during the workshop. While at the start of the project, teachers reported low levels of familiarity with project topics (average: 1.82/4), by the project's conclusion, teachers reported higher levels of familiarity with project topics (average: 2.97/4), indicating general familiarity with the topics. The average reported increase for the mechatronics items was 1.15. The pre-/post-survey also included 7 items on familiarity with areas of business, intellectual property, and innovations. While at the start of the project, teachers reported moderate levels of familiarity with project topics (average: 2.08/4), by project's conclusion, teachers reported higher levels of familiarity with project topics (average: 3.06/4). In this case, the average reported increase was 0.98. See Figures 10 and 11 for additional details.

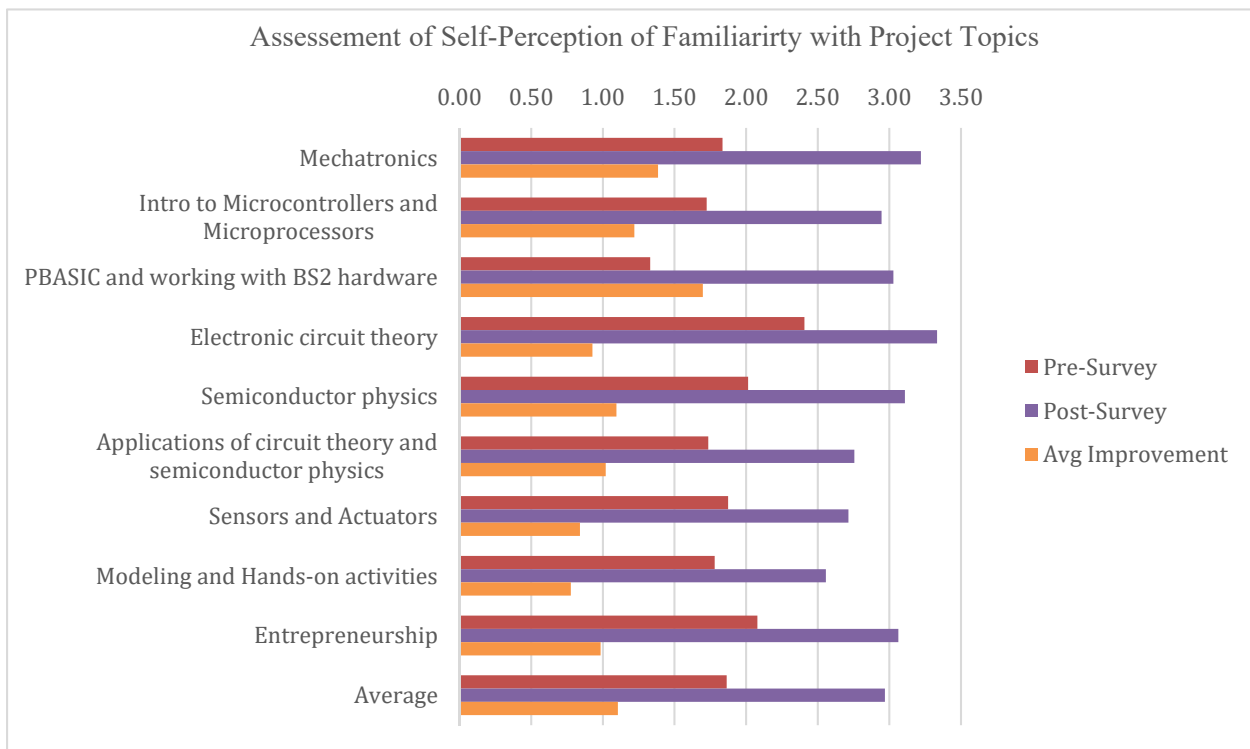


Figure 10: Assessment of teachers' self-perception of familiarity with project topics

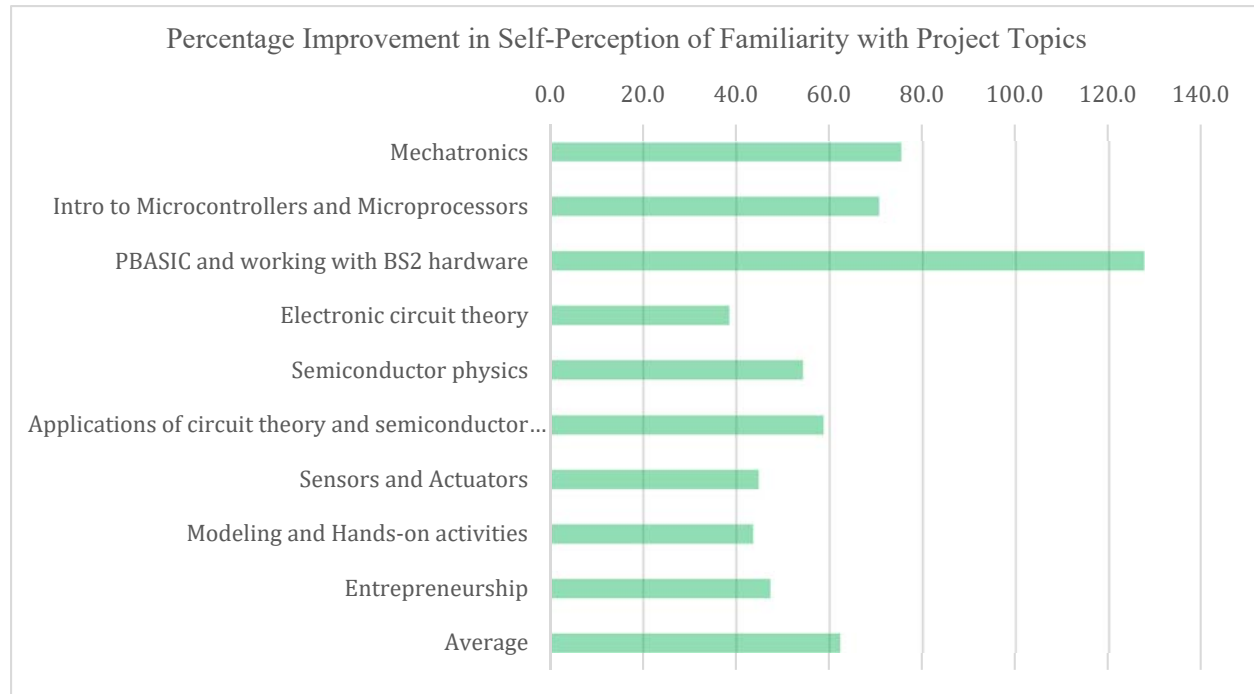


Figure 11: Percentage improvement in teachers' self-perception of familiarity with project topics

Teachers were divided into four research labs; with three labs hosting two teachers each and one lab hosting three teachers. During interviews, they described what they had accomplished, what they had learned, and how they expected to use their experiences. Interviews were conducted with each of the teachers and they were then visited at their research lab sites. Several teachers described their learning and use of computer programming, in particular with MATLAB and CAD software. They had spent a great deal of time developing and testing the products on which they worked, in the following areas.

- To guide robotic fish, and to fabricate waterproof materials in which to enclose the robots.
- To capture cells in channels made to certain specifications.
- To transmit signals to robots that worked in swarms.
- To provide instructions so that robots would walk as instructed.

By visiting the labs and holding further discussions, the evaluator could observe in action what teachers had described earlier in the day. In each case, it was clear that the teachers had put into practice what they had learned, developing practical products by employing the theory studied. The teachers who worked with robotic fish (subsection 4.3), also fabricating materials to certain specifications, demonstrated their work. The two teachers fabricating plastics with channels for trapping single cells (subsection 4.4) explained their work. Their graduate student mentors showed with microscopes the actual materials and further explained the development. The project mentor for the group working on swarming drones (subsection 4.5) offered a clear explanation of how the

drones were programmed to be in contact with one another, with no single drone having contact with all of the others. Teachers were enthusiastic, assisting in answering the evaluator's questions and describing what they had learned. The evaluator also noted that high school students who were participating in this drone project collaborated with teachers. The teachers working on the walking robots (subsection 4.7) had spent a lot of their time in the MakerSpace. They demonstrated what their robots were able to do and explained what they had learned. They said that they would like to have accomplished more, but described the painstaking efforts in analyzing motion, fabricating materials, developing computer instructions, and testing electronic interactions. In the future, the project team will offer additional mentorship to address these challenges to ensure high teacher efficacy.

One teacher reported the importance of creating different assessments goals for students throughout a science project in order to support students' learning progression and identification of misconceptions. This teacher's newfound understanding of creating assessments that looks at students' learning progressions was due to her own learning and research experience in this PD program. Several teachers communicated that the improvement in coding and programming would be important in their classes and in computer clubs. When asked how experience and knowledge from the summer would impact their teaching, the respondents mentioned the importance of "real world" experiences, making learning more relevant to students, and adapting material so that the projects would be more teachable as part of coursework or computer clubs. Other comments from teachers are included below.

- Knowledge of industry helps me make real world connections to the subject material I am teaching.
- Knowing more about business and industry will make abstract concepts more relevant to students by placing them in a context and showing how they may be impacted.
- I think I am able to get a better feel for how computer science and engineering are applied to real world scenarios.

Seven participants responded to a survey item that asked about their greatest challenges in teaching. They reported the following challenges: classroom management (3), differentiation of instruction (1), and project-based learning, greater use of technology, and preparing students for the technological world (3).

The project team administered a technical quiz at the start of the two-week hands-on training to assess teacher's math/science concepts and understanding of engineering fundamentals *vis-a-vis* mechatronics. After the completion of the four-week research phase, the same technical quiz was given to assess any post-project improvement among the teachers. Based on these pre-/post-project technical quizzes, it was found that the teacher's understanding of scientific, mathematical, and engineering foundations of mechatronics concepts improved from 49% to 64%, producing 30.6%

improvement. Further analysis conducted on the quiz results using a paired t -test resulted in a t value of 3.702 and a corresponding p value of 0.006, indicating that the null hypothesis can be rejected and the results are significant with a significance level higher than 99%.

The following relevant themes emerged from the survey data, interviews, and observations.

Mechatronics and research: All of the teachers reported participating in some previous research. Their earlier experiences taught them the importance of patience and perseverance and these qualities were noted in interviews and lab visits. Mechatronics was new to most of them, as reflected in the pre/post inventories. However, they had enough related knowledge to be able to understand the theory and practice of the field, and to use these in their research projects.

Robotics and take back: Interviews suggests that teachers generally had one eye on their summer projects and the other on their classrooms and computer clubs at school. This thinking reflects positively on the program. Teachers' descriptions of how they would use, for example, programming, soldering, 3D printing, robotic movements were all explained in ways that made it clear that they were poised to take their students from "reading about" to doing science, and from classrooms to labs and computer clubs.

Business mindset: Teachers reported that the business and entrepreneurial activities provided an important new dimension to their learning and teaching. They felt strongly that these ideas and experiences would add a practical dimension that would motivate their students. Teachers reported that they can now confidently answer students' questions relating to "real world" use of science, which arise even in areas as interesting as robotics.

Ongoing learning: Several of the teachers commented that ongoing learning, as experienced in the summer PD, is important for teachers. If they are to appreciate the difficulties and practical issues involved in their students learning new material, they must themselves be engaged in learning. In addition, several of the teachers talked about their commitment to long-term learning in areas such as computer programming.

7. Academic Year Follow-up

In fall 2017, on a school holiday, a day-long follow-up event was conducted during which the teachers presented their summer research experience and NYU SoE researchers presented their progress on research projects from the summer. Additionally, teachers participated in a 4-hour workshop on Raspberry-Pi, learning valuable insight into the basic operation, applications, and benefits of the credit-card sized minicomputer. Each teacher received four additional project kits to use for hands-on activities with their students in the classroom.

Faculty mentors and graduate researchers further collaborated with teachers by visiting their schools and assisting them in implementing their newly acquired skills. During these visits, the graduate researchers discussed their STEM research and shared their experiences in the STEM field. Moreover, the visits provided an opportunity for the high school students to interact with researchers and understand the career path and job prospects for a STEM graduate.

The graduate researchers' visits have assisted teachers in organizing robotics activities and teams for their schools and enabled students interested in participating in robotics contests to consult with researchers about expectations, commitments, and technical aspects to be successful in such activities. As a result, many of the PD participants have started robotics clubs for their schools' students. Collectively, these educators are impacting over 120 students, vast majority of who come from weaker socio-economic backgrounds, with approximately 50% being women and 90% from underrepresented minority groups. These educators have acted as mentors to the robotics clubs and they have developed and implemented lessons and activities based on the PD curriculum from the guided-training phase of the program. They have continued to use the mechatronics and robotics kits provided through the PD program and have procured additional robotics kits and components through resources from their own schools. The activities of these student clubs are being organized once or twice every week in after school hours. The students are being engaged to actively work on designing, programming, and testing robots and learning the various STEM concepts associated with robotics.

In addition to the aforementioned robotics club activities, one teacher (Mr. A.R.) has guided a student team to participate in the Robocup Jr. competition. Experience from the program allowed the teacher to experiment on the robot's design. The teacher is now developing an improved prototype using a Raspberry-Pi, ROS, and a camera, versus the older robot that relied on LEGO NXT sensors. Several teachers have continued their research collaboration with engineering labs beyond the 4-week research program. These follow-up interactions offer further evidence of the effectiveness of the program in engaging participants through real-world research and learning experiences.

8. Conclusion

The teacher PD program was successful in many areas, building on teachers' interests and experiences. The program was well planned bringing professionalism to the study of engineering concepts while treating teachers as colleagues and partners, thereby creating a trusting teacher-scientist relationship. All the aforementioned results are notable since the NGSS includes the implementation of SEPs in science teaching and learning. Implementing the NGSS requires extensive planning and collaboration with school administrators, teachers, and PD program providers. Science teachers require extensive support on how to plan and execute lessons that include the NGSS 3D learning model. For example to fully implement SEPs in the science

classroom, teachers must address all eight practices [5]: (1) asking questions (for science) and defining problems (for engineering); (2) developing and using models; (3) planning and carrying out investigations; (4) analyzing and interpreting data; (5) using mathematics and computational thinking; (6) constructing explanations (for science) and designing solutions (for engineering); (7) engaging in argument from evidence; (8) obtaining, evaluating, and communicating information. In order for teachers to effectively implement all eight SEPs, it is critical that they themselves engage in the said practices, experience scientific discoveries, and explore the nature of science. As seen in Section 6, teachers' understanding of scientific, mathematical, and engineering foundations of mechatronics concepts improved by 30.6% after engaging in this engineering research PD program. This PD program explicitly addresses the new standards by intricately and purposefully embedding SEPs, DCIs, and real-world industry practices.

Results suggests that through modeling what scientists do and connecting engineering content to the new national standards, teachers' agency in science and math increased. Teachers in our federally-funded PD program requested further collaboration with STEM professionals to develop their own robotics labs, reported increased content knowledge in math and science concepts, and discussed the benefits of the teacher-scientist relationship. In addition, engaging teachers in hands-on activities focusing on real-world applications gave them an opportunity to hone their science and math skills. Furthermore, supporting teachers in these scientific inquiry opportunities, and highlighting the importance of entrepreneurship, is an area of research needed for effective science teaching and learning. Further studies in engineering education that highlight ways to explicitly support teachers in implementing NGSS in their science classrooms is crucial, specifically enacting lessons using NGSS CCs to explicitly connect all science subject areas. It is our future goal to work with teachers and researchers to address the 3D performance expectations of NGSS by creating specific research opportunities for teachers and identifying SEPs 1-8 and supporting them to create lessons that address students' misconceptions and use CC's to introduce students' to the natural phenomena.

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