2021 ASEE ANNUAL CONFERENCE
Virtual Meeting | July 26–29, 2021 | Pacific Daylight Time
Paper ID #33508

Project in a Box: Self-Contained Instructional Hands-On Kits for Electrical Engineering Outreach

Ms. Phuong Truong, University of California, San Diego

Phuong Truong is currently a fifth year PhD candidate in the Department of Mechanical and Aerospace Engineering at UC San Diego. Following her passion for research and education, she has worked closely with faculty at the Jacobs School of Engineering since 2016 to develop and improve curriculum for experiential learning courses. Her areas of focus include experiential learning, curriculum design, outreach program design, and engineering leadership.

Nicholas Stein, University of California, San Diego

Works as the Project Development and Outreach Coordinator for the Electrical and Computer Engineering Department at UC San Diego.

Prof. Truong Nguyen, University of California, San Diego

Truong Nguyen is a Distinguished Professor at UCSD. His current research interests are video processing and machine learning algorithms with applications in health monitoring/diagnosis and 3D modeling. He received the IEEE Signal Processing Paper Award for the paper he co-wrote with Prof. P. P. Vaidyanathan on linear-phase perfect-reconstruction filter banks (1992). He received the NSF Career Award in 1995.

While serving as department Chair (2014-2019), Prof. Nguyen and several faculty and student tutors developed a comprehensive hands-on curriculum for the ECE Dept. that emphasizes system-thinking and human-centric design. He is currently working on several projects with minority serving institutions on improving students enrollment in STEM fields.

Project in a Box:
Self-Contained Instructional Hands-on Kits for Electrical Engineering Outreach

Phuong Truong, Nicholas Stein, Truong Nguyen
Department of Electrical and Computer Engineering
University of California, San Diego

Abstract

In this paper, we report on a self-contained project kit platform for hands-on learning in outreach programs and experiential environments that overcomes barriers to entry in learning electrical engineering topics such as programming, circuits, and hardware. These kits, referred to as, "Project in a Box" or PiB kits, teach a myriad of electrical engineering topics, including basic control theory, robotics, circuits, electronics, and programming. The step-by-step manual with 3D visual aids and comments, allows untrained students, parents, and faculty to follow along given the provided kits. We have successfully deployed PiB kits in courses, programs, outreach workshops, public library workshops, and faculty outreach training seminars. The target demographic of these kits ranges from middle school to first-year college students. This paper highlights our results from our flagship Family Program and community outreach. The Family Program and Library Program deploys these kits through a series of workshops aimed at raising awareness in electrical engineering for parents and children and encourages teamwork in families through hands-on projects. Both programs encourage participants to become the teachers of their community further proliferating the efforts to encourage STEM.

Introduction

It is an exciting time in STEM education as more technologies have become affordable and readily available with online support structures and forums [1-4]. Teaching and engaging the younger generation of students to encourage a pathway to engineering is still of importance to our national STEM efforts and is easier now with available open-source technological tools and platforms such as Arduino, BeagleBone, and Raspberry Pi [5-7]. However, there remains a barrier to entry as many available technologies or kits in electrical engineering require a well-versed person in the areas of engineering, technology, or science to understand and follow the instructions [8-9]. Electrical engineering encompasses complex topics such as circuits, programming, hardware-software interfacing, controls, systems, and much more [10-11]. Such advanced topics are difficult to teach, and at present, not very approachable for student demographics in middle school to community college, a vital period in which students make decisions related to the STEM path [12]. In this paper, we explore the Arduino, a widely used open-source hardware platform for teaching and create documentation that makes learning electrical engineering topics easy, familiar, and approachable. While the resources for the Arduino are vast, diverse, and readily available, it can be overwhelming for students, instructors, teachers, and program organizers. Specifically, it can be overwhelming as a beginner to think about where to start, what concepts to target first, and which components to purchase, especially for complex concepts in electrical engineering. The PiB kit documentations provide a self-contained way to teach and learn using commercially available technologies. We design hardware kits around the Arduino that teaches circuits, programming, and hardware in an IKEA-style documentation. All required components and documentation needed to complete the projects are self-contained in each kit and allow students to work at their own pace to finish the project. We deploy these kits in various outreach programs and measure the number of completion of the kits and general satisfaction of the participants.

Project Kit Design Overview

The hardware platform selected for the base of all project kits is the Arduino, a programmable single-board microcontroller, typically used for basic prototyping [13]. Figure 1a and 1b show the Arduino Nano, a small form factor (18 x 45 mm) microcontroller, one of many Arduino models commercially available. Arduino was selected as the platform of choice because it has been widely adopted and used in classrooms [6], has a large and supportive online community due to its open-source platform [14], and the hardware interfaces with a simple and free IDE (integrated development environment) software where the students can easily program the microcontroller board [8].

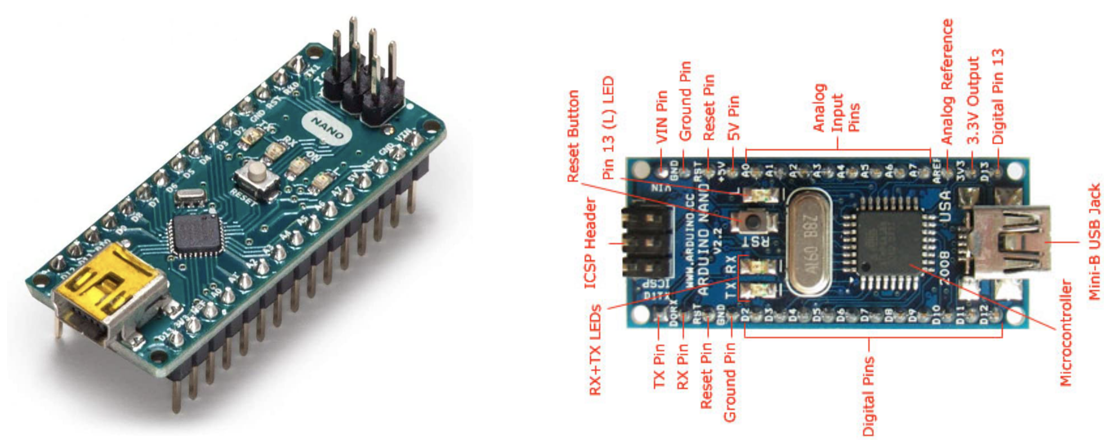

Fig. 1 (a) Arduino Nano used in the Project in a Box (PiB) kits. General pin layout of the Arduino Nano [15-16].

Each PiB kit allows students to work on a particular electrical engineering concept (programming, robotics, circuits) within the larger context of a system. Specifically, while students are learning concepts such as resistance, current, voltage, they are also learning how the circuit can be controlled through programming, and is embedded into a structure or mechanical system that they can spatially visualize in the 3D renderings of the documentation. Through building these kits, they understand the interconnectivity, complexity, and context in which the elements work together. When put in teams of two, students quickly realize that in order to complete the kit in a timely manner, one student should program the system and the other should assemble the hardware. Both students must communicate in synchrony in order for the hardware and software to interface properly.

Figure 2 shows eight PiB kits that have been developed and used in outreach workshops and programs. In general, the major components used in all of the kits include: laser cut wood pieces, the arduino nano, a breakout shield, motors or servos, sensors, wires, basic circuit elements (LEDs, resistors, buzzer), and batteries. The pieces (originally unassembled) are packaged and placed in a box with documentation in preparation for workshops. Raw materials cost approximately $30-50 US dollars on average for each kit. Each kit can be completed in approximately 3-4 hours with two participants working together.

The description for the eight kits shown in Fig. 2 are as follows:

- **Introduction to Arduino**: An introduction to basic electronics, programming, and hardware. Students learn how to use the Arduino to interface with basic circuit elements such as LEDs, buttons, and sensors (photo-resistors, soft potentiometers). Students also learn how to utilize the Arduino IDE, program in Arduino C, and build their own .cpp / .h libraries.
- **Magic 8 Cube:** A magic 8 cube that predicts the future! Students learn to program an Arduino Nano to obtain readings from a vibration sensor and display on an OLED (organic light-emitting diode). Students learn how to program switch statements and collect and process sensor data.
- **Ladabot:** A walking, dancing robot. Students learn to program an Arduino Nano to obtain sensor readings from an ultrasonic sensor and translate them to walking and dancing motions through servo actuation. Students learn how to calibrate servos, mechanical assembly, and programming.
- **Ardubot**: A wall avoiding robot. Students learn how to use the Arduino Nano to program if-else statements and control robot movement (turning, stopping, avoiding objects, etc.).
- **Candy Sorter**: Students learn how to program and calibrate RGB color sensors and basic servo actuation to coordinate dispensing with precise drop location for sorting.
- **Photo-Theremin**: Students learn about circuits, resistance, current, and voltage using basic circuit elements such as photo resistor, capacitors, resistors, and buzzer to wire their own photo-theremin to create sci-fi sounds based on how far or close their hand is positioned from the photo-resistor.

- **Fargbot:** A color determination robot. A variation of the RGB color sensing kit (candy sorter). Students program and calibrate a RGB color sensor to determine the color of the object placed into the mouth of the robot. An RGB will light up with the corresponding color of the object.
- **Linjebot**: A line following robot. Students learn to program and calibrate line sensors and tune their PID (proportional, integration, derivative) controller. Students adjust potentiometer settings to change the PID error constants and follow various obstacle pathways.

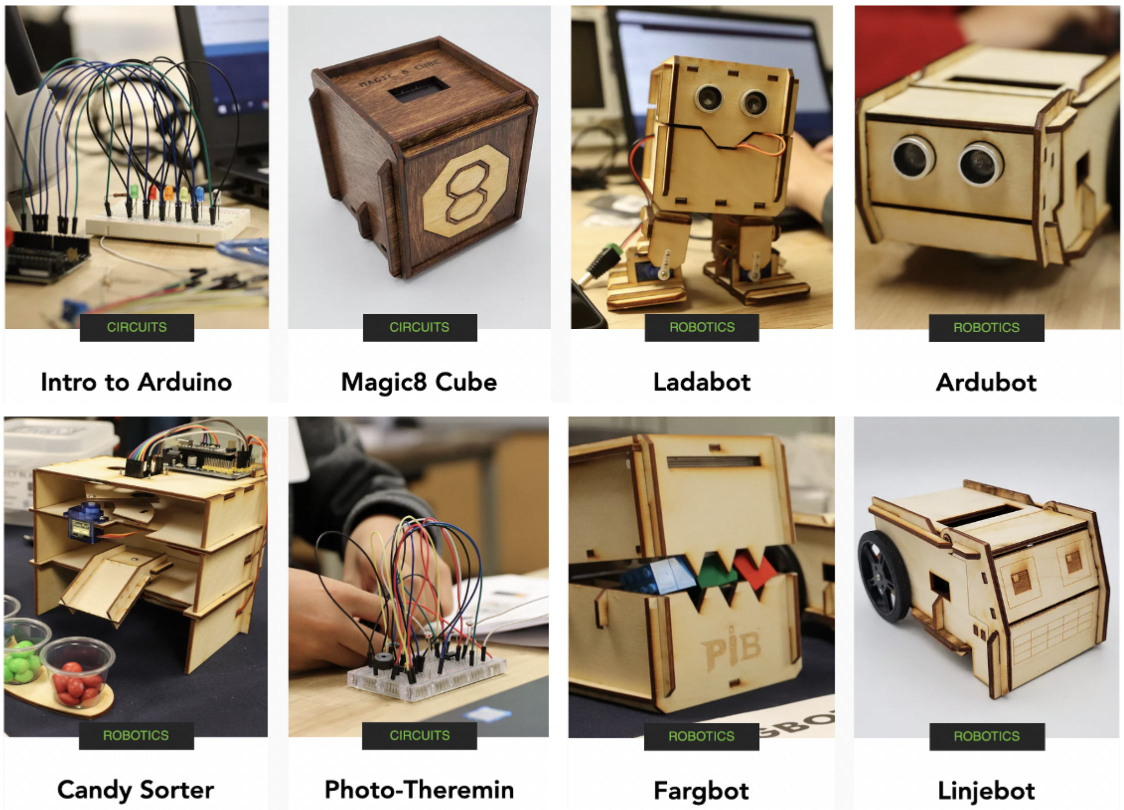

Fig. 2. Project in a Box kit collection used as an instructional platform in outreach workshops and programs.

Documentation

While the kits themselves are inspired by online DIY projects, the documentation allows the participants to follow at their own pace and work through the steps of assembly and programming in the kit.

The standard documentation begins with safety instructions regarding using the components and tips and tricks to navigate through the assembly process. Next, download and installation instructions are introduced to ensure students or instructors are prepared for the programming part. The rest of the documentation covers step-by-step instructions with 3D visualizations that resemble IKEA furniture assembly instructions to support students, parents, and instructors with a familiar and easy to read manual. Fig. 3 shows typical pages found in the documentation booklet that accompany the hardware kit.

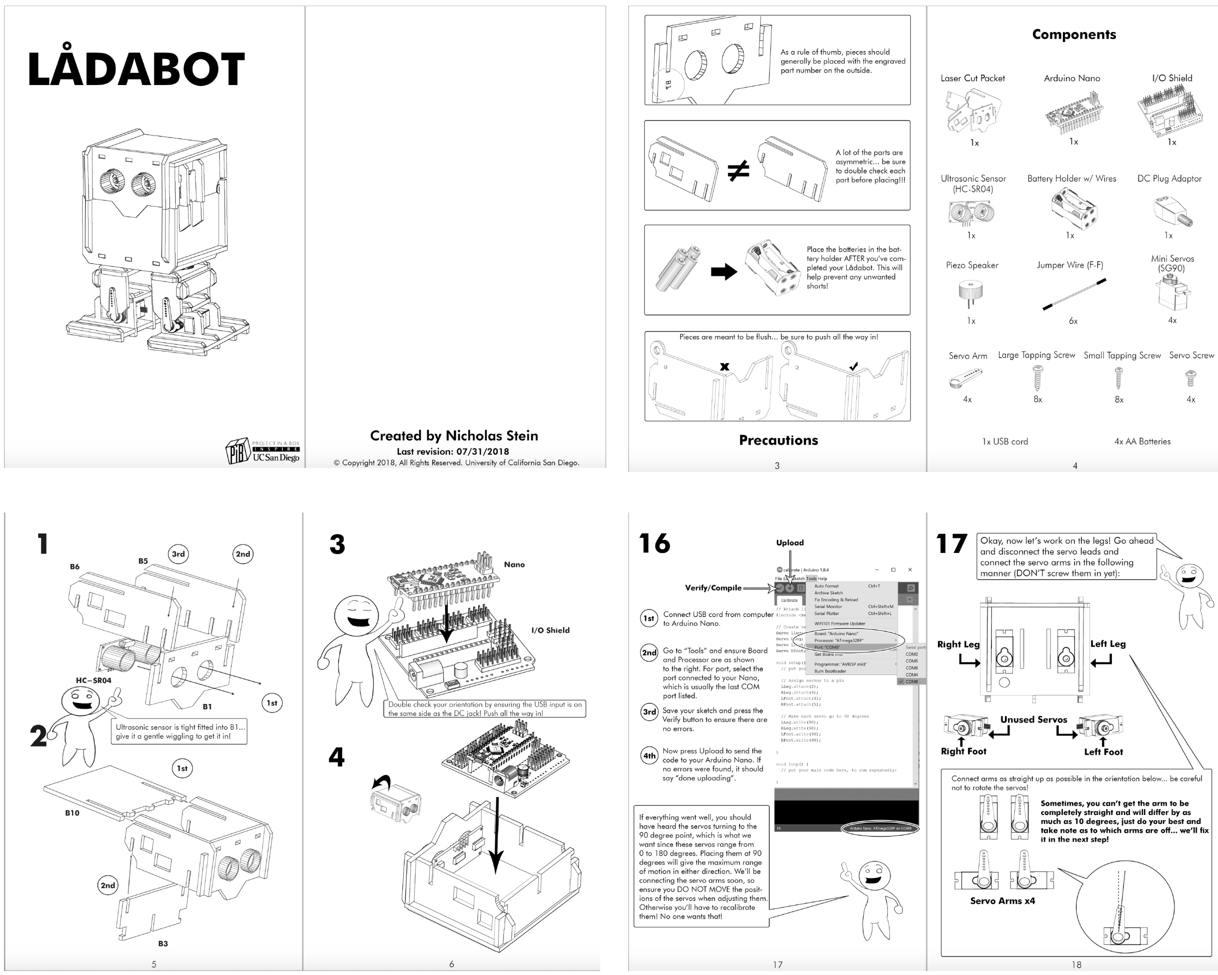

Fig. 3. Typical pages of documentation for the PiB kits that show students how to assemble hardware and how to work with software to program the components.

Workshop Implementation

We highlight two flagship programs launched in the summer of 2018, winter of 2019, and summer 2019: the Family Program and the Library Program. Combined, these program workshops had over 100 new and recurring participants and were organized 25 times.

Each workshop was organized with one lead instructor and approximately five engineering students to mentor the parents and children (1:5 mentor to children ratio). The mentors were there to help in providing hardware failure replacement and support as well as troubleshoot. The documentation allows the groups to work at their own pace and call on a mentor as they need help. This provides a sense of space and independent learning while allowing sufficient support to ensure project completion.

The Family Program initiative aimed to provide a fun and educational environment for parents with children in middle school or high school to spend time together through engaging hands-on projects. PiB kits were used as a vehicle and platform to achieve these goals through a series of workshops that invited parents with middle school or high school children throughout San Diego county. Parents arrive with their students and work on the kits together at each workshop.

The Library Program aimed to mobilize the parents and students from the Family Program to give back to their community. Parents and students from the Family Program were invited to help tutor and mentor other families and students at a local library in which family workshops were organized. In this way, the programs support proliferating the spirit of STEM and specifically, engineering, to empower and encourage parents and students to take the knowledge they learned and teach and give back to their own community.

Results and Discussion

Assessment is measured by percentage of completed kits, as completing the kits demonstrate competency in the target learning areas and ability to recreate the projects as intended. Based on over 25 workshops and over 100 recurring participants, we have over 85% success rate of completion. Completion was the only metric measured to determine if the documentation was provided the support needed to start and finish the project. Those who were not able to complete the project had issues primarily due to part failure more so than confusion of the instructions. On the instructing side, the kits have been tested with both experienced (prior experience with outreach projects) and inexperienced (first time) instructors yielding similar success rates. Generally, students who are not able to complete the project were not due to the lack of guidance or deficiencies in the documentation, but due to inevitable hardware failures from servo malfunction or nonresponsive sensors. Fig. 4 shows images from the programs.

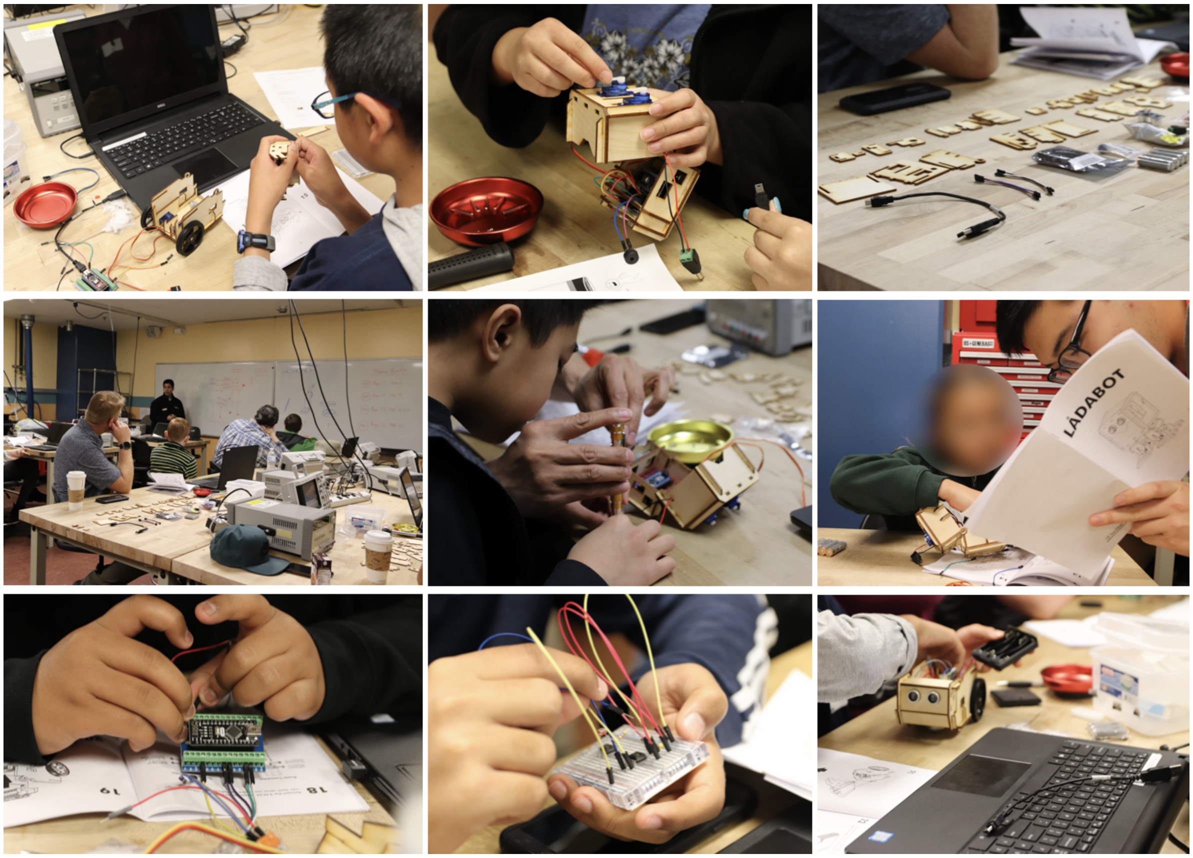

Fig. 4. Photos of students and parents working on PiB kits at the family workshops.

Future Work and Direction

We highlight the instruction manual and self-contained hardware kit as a platform for scaling and replicating these programs in other universities and programs. The PiB kits provide a way to learn complex electrical engineering concepts in a fun and engaging way through approachable hands-on projects and easy to read documentation. Our future work includes expanding the kits to include more advanced concepts in electrical engineering such as machine learning and wireless communication. While testing student efficacy could be a point of study in the future, our goals for these project kits are to inspire, expose, and engage our younger generation to electrical engineering. These kits are designed to be adoptable and approachable as outreach instructional platforms and thus testing conceptual mastery is not our focus.

We also aim to expand our outreach efforts to deploy hardware for remote workshops through large library networks (San Diego Library) or institutions (Institute of Americas). Our work with these existing organizations will be both regional and international with our documentation delivered both in English and in Spanish.

References

[1] Karaahmetoğlu, Kübra, and Özgen Korkmaz. “The Effect of Project-Based Arduino Educational Robot Applications on Students' Computational Thinking Skills and Their Perception of Basic Stem Skill Levels.” *Participatory Educational Research*, vol. 6, no. 2, 2019, pp. 1–14., doi:10.17275/per.19.8.6.2.

[2] Chang, Chi-Cheng, and Yiching Chen. “Using Mastery Learning Theory to Develop Task-Centered Hands-on STEM Learning of Arduino-Based Educational Robotics: Psychomotor Performance and Perception by a Convergent Parallel Mixed Method.” *Interactive Learning Environments*, 2020, pp. 1–16., doi:10.1080/10494820.2020.1741400.

[3] Mayorova, Vera, et al. “New Educational Tools to Encourage High-School Students' Activity in Stem.” *Advances in Space Research*, vol. 61, no. 1, 2018, pp. 457–465., doi:10.1016/j.asr.2017.07.037.

[4] Susilo, Ekawahyu, et al. “STORMLab for STEM Education: An Affordable Modular Robotic Kit for Integrated Science, Technology, Engineering, and Math Education.” *IEEE Robotics & Automation Magazine*, vol. 23, no. 2, 2016, pp. 47–55., doi:10.1109/mra.2016.2546703.

[5] Tseng, Kuo-Hung, et al. “Attitudes towards Science, Technology, Engineering and Mathematics (STEM) in a Project-Based Learning (PjBL) Environment.” *International Journal of Technology and Design Education*, vol. 23, no. 1, 2011, pp. 87–102., doi:10.1007/s10798-011-9160-x.

[6] El-Abd, Mohammed. “A Review of Embedded Systems Education in the Arduino Age: Lessons Learned and Future Directions.” *International Journal of Engineering Pedagogy (IJEP)*, vol. 7, no. 2, 2017, p. 79., doi:10.3991/ijep.v7i2.6845.

[7] Yamanoor, Narasimha Saii, and Srihari Yamanoor. “High Quality, Low Cost Education with the Raspberry Pi.” *2017 IEEE Global Humanitarian Technology Conference (GHTC)*, 2017, doi:10.1109/ghtc.2017.8239274.

[8] Jalden, Joakim, et al. “Using the Arduino Due for Teaching Digital Signal Processing.” *2018 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, 2018, doi:10.1109/icassp.2018.8461781.

[9] Riojas, M., et al. “Educational Technologies for Precollege Engineering Education.” *IEEE Transactions on Learning Technologies*, vol. 5, no. 1, 2012, pp. 20–37., doi:10.1109/tlt.2011.16.

[10] J. A. Momoh, "Outreach Program in Electrical Engineering: Pre-College for Engineering Systems (PCES)," in *IEEE Transactions on Power Systems*, vol. 29, no. 4, pp. 1880-1887, July 2014. doi: 10.1109/TPWRS.2014.2320279

[11] Artis, Sharnnia, and Gregory Washington. “Design, Code, Build, Test: Development of an Experiential Learning Summer Engineering and Computer Science Outreach Program for High School Students (Evaluation).” *2017 ASEE Annual Conference & Exposition Proceedings*, doi:10.18260/1-2--28122.

[12] Blotnicky, Karen A., et al. “A Study of the Correlation between STEM Career Knowledge, Mathematics Self-Efficacy, Career Interests, and Career Activities on the Likelihood of Pursuing a STEM Career among Middle School Students.” *International Journal of STEM Education*, vol. 5, no. 1, 2018, doi:10.1186/s40594-018-0118-3.

[13] Prima, E C, et al. “STEM Learning on Electricity Using Arduino-Phet Based Experiment to Improve 8th Grade Students’ STEM Literacy.” *Journal of Physics: Conference Series*, vol. 1013, 2018, p. 012030., doi:10.1088/1742-6596/1013/1/012030.

[14] Herger, Lorraine M., and Mercy Bodarky. “Engaging Students with Open Source Technologies and Arduino.” *2015 IEEE Integrated STEM Education Conference*, 2015, doi:10.1109/isecon.2015.7119938.

[15] “Arduino.” *Arduino Nano Canada Robotix*, Http://Excesstext.com/2016/10/16/Problems-Updating-Emax-Nano-Escs/Dacgs/.

[16] “Arduino Nano.” *Excess Text*, http://Excesstext.com/2016/10/16/Problems-Updating-Emax-Nano-Escs/Dacgs/.