ASEE 2022 ANNUAL CONFERENCE
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MINNEAPOLIS, MINNESOTA, JUNE 26TH-29TH, 2022 ASEE
Paper ID #37400

Effectiveness of a Virtual-Physical Robotics Teaching Platform on Engaging Middle-to-High School Students during COVID-19 (Evaluation)

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Amanjeet Bagga is pursuing a B.E. in Mechanical Engineering at Stony Brook University and a part of the class of 2024. A survivor of Acute Lymphoblastic Leukemia, he wishes to design innovative robotic toys that can help children suffering from cancer both emotionally and functionally. In the future he intends to pursue a M.S. in Mechanical Engineering while focusing on product design so he can tend to his goals sooner than later.

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Abstract

This paper presents design, implementation, and evaluation of a novel virtual-physical summer Robotics camp for 7th-12th grade students offered by the Manufacturing and Technology Resource Consortium (MTRC) at Stony Brook University during the COVID-19 pandemic*. The MTRC is New York state's Empire State Development's Regional Manufacturing Extension Partnership (MEP) center for the Long Island region. While this program had been offered in person in 2018 and 2019, in 2020 and 2021 due to the pandemic, it was offered online only using a virtual-physical robotics platform. The modality of this platform consisted of a novel hardware kit, which was shipped to students in advance, a web-based robot motion design software, and a curriculum which brought the hardware and software together. This paper presents a study on the feasibility and accessibility of this program and its effectiveness in engaging students and exposing them to key robotics concepts while helping them make suitable career decisions. The pre- and post-program surveys indicated that the students' interest in a STEM field increased as a result of this camp, helped them understand that robotics is much more than just programming, and taught them mechanical design, practical electronics, and microcontroller programming in a flipped and experiential learning format. Moreover, survey results also indicated an attitudinal shift in their decision making based on the knowledge, skills, and capabilities that they acquired in the camp.

1 Introduction

Papert's Constructionist theory [1] and Kolb's theory of experiential learning [2] provide the impetus for engaging students in hands-on, active learning experiences to build self-motivated knowledge structures. Robotics lies at the intersection of various engineering disciplines and provides the perfect platform for students, makers, and hobbyists to learn about STEM topics (Beer et al. [3], Eguchi [4], and Khanlari [5], Crowe [6]). Robotics in schools, colleges, and informal learning environments has the greatest potential to create a workforce that is prepared to tackle the technical challenges of the 21st century and drive our innovation-based economy. It could help high-school students be well-prepared for taking STEM courses in colleges and help fill millions of STEM jobs that are currently vacant.

Despite the obvious benefits to teaching Robotics, very few K-12 schools in the nation offer Robotics as a subject at an early stage. Studies show that the price of components or ready-

*https://www.stonybrook.edu/commcms/mtrc/robotics/camp.php made kits for making robots is a barrier for many youth and adults who want to participate in hobby or educational robotics [7], while the schools hesitate to buy expensive robot kits that do not provide significant learning opportunities. Consequently, the state-of-the robotics education in K-12 schools is either coding-focused or competition-based, both of which do a disservice to students who are not interested in either. However, they might still be interested in what robotics has to offer much more broadly, viz., engineering design, electronics, and computational thinking. This gap has been partially filled by the after-school or summer robotics program, yet they also suffer from the same problems of access and affordability. Nonetheless, short duration summer STEM programs have proven valuable in engaging students and inspiring them to select a career in science, technology, engineering, and mathematics.

In light of these opportunities, several universities have often offered summer STEM-based robotics programs to K-12 students. Ayar et al. [8] presented a robotics summer camp for high-school students with a view to increase the students' interest in engineering and to help them choose a specific engineering major in the future. Naz and Lu [9] reported a summer STEM camp for high-school girls to help them learn about fundamentals of science and engineering in a project-based setting. Miller et al. [10] emphasized the role of robots in solving problems as a motivator for girls in a summer program. Faber et al. [11] created a multi-year engineering program to help inspire middle and high school students to pursue a career in STEM, and to academically prepare them to succeed in college. Stansbury and Behi [12] presented a curriculum for a summer robotics program, which culminated in a robot battle-bot competition and a robot talent show. Rahman et al. [13] discuss the fundamental requirements for middle school students to successfully participate in robotics-based STEM lessons. In particular, they draw attention to formally inquiring the prerequisite knowledge, skills, attitude, and abilities that learners need to succeed in such programs. Burack et al. [14] presented results of a multi-year longitudinal study of after-school robotics programs operated by FIRST, an organization which stands "For Inspiration and Recognition of Science and Technology". In particular, they sought to measure impact on student attitudes towards STEM and STEM careers and related courses. While they found that the graduates of FIRST focused more on the E and T of the STEM and were more likely to choose a career focused on engineering and technology, they also acknowledged the self-selection bias inherent in the students of FIRST. Barger et al. [15] presented details of their summer robotics camp, which was designed to arouse student interest in advanced manufacturing through robotics in an experiential learning environment.

The aforementioned studies clearly show that Science, Technology, Engineering, and Math (STEM) and Robotics summer camps are highly sought after by parents of children in K-9 grades. These camps serve as a tool to kindle children's interest in STEM disciplines. Like in several studies discussed above, the MTRC Program at Stony Brook University has been organizing a summer robotics camp, which introduces students from 7th to 12th grade to the fascinating world of robotics. This fully sponsored program introduces students to the three core elements of robotics: mechanical design, practical electronics, and microcontroller programming while helping them learn the valuable 21st century learning skills, viz. critical-and creative-thinking, communication, and collaboration in teams. This camp ends with a team-based capstone design presentation, where students do not compete with each other, but present their own solution to a thematic challenge and demonstrate their knowledge and skills acquired in the camp.

Considering the hands-on nature of this camp, and of robotics in itself, the MTRC Program's ability to continue during the summer of 2020 was in question due to the COVID-19 pandemic.

However, determined to provide this valuable experience to the students, the program pivoted from its in-person offering to an online hybrid model of teaching in conjunction with a novel robotics education platform. This platform facilitated the virtual summer program by utilizing a combination of unique, low-cost hardware, which students were sent and then allowed to keep at the end of the program while utilizing a web-based robot design software to help them learn the design process. While physical robot kits were shipped out to students at their home, instructor-student and student-student interaction took place virtually. The hybrid style utilized in this program allowed students to develop self learning skills outside of the synchronous sessions, while utilizing live interactions to engage in discussions and problem solving. While students have enough experience in the lecture format through years at school, this hybrid model helped develop useful skills for post secondary education, where independent learning is a key component to students' success. To the authors' best knowledge, when all such hands-on activities, which were largely seen as optional and mere enrichment, were halted during the pandemic, the MTRC program successfully implemented and delivered a summer robotics program to students deprived of any significant experiential learning experience while staying at home. Seeing the success of the program in 2020, the sponsor decided to expand it to include all NY-state students in the summer of 2021.

In the virtual offering of this program in the summer of 2020 and 2021, a total of 90 students (30 in 2020 and 60 in 2021) participated in the three-weeks long robotics program that concluded with a unique capstone project where they were asked to employ design thinking in identifying a COVID-19 related problem for someone negatively affected by the pandemic and thereafter design and build an autonomous or remote-controlled robotics solution. This approach was markedly different from other competition- or challenge-based robotics programs since students were asked to use an empathy-driven approach to identify problems. Problems ranged from tedious and tiring jobs of disinfecting surfaces, delivering drugs in hospitals or packages autonomously, or entertaining children and elderly in socially distant times.

This paper discusses the details of this program's offering in the summer of 2020 and 2021, which sought to 1) solve the issue of accessibility and feasibility of a hands-on STEM program during the pandemic and 2) study the self-reflective attitudinal shift in school courses, STEM preparedness, and college career choices. While the students' attitude can be hard to quantify and interpret, through the post-camp survey, we seek to answer the question of their preparedness and proficiency in engineering design, electronics circuit, and computer programming in the context of robot design.

The rest of the paper is organized as follows. First, we present a summary of the STEM imperative and its relation to educational robotics. Our goal in this section is not to present an in-depth analysis of STEM education, but some insights as they relate to effective STEM educational models, the state-of-the science and engineering education in K-12, the poor positioning of STEM education which could lead to disillusionment among students, and on the role of engineering in school curriculum. In the next section, we present the design and implementation details of this program. Finally, we present the data collection and analysis before concluding this paper.

2 STEM Imperative and Educational Robotics

The goals of the MTRC Robotics camp were to 1) introduce 7th-12th grade students to three major engineering disciplines and 2) excite and engage them to learn practical electronics, mechanism design, and microcontroller programming in the context of robot design, and 3) motivate them to adopt a STEM career and become scientifically literate citizens. These goals are rooted in effective STEM education, which seeks to build a cognitive and skill-based framework for students' learning. However, how to build an effective STEM education model and associated curriculum is still an open topic. Widya et al. [16] have presented three implementations of STEM Education models as "SILO", "Embedded," and "Integrated". In the SILO model, each subject is isolated, and the teacher leads the classroom to *teach* rather than to help students learn by doing. The Embedded model is based on real-world problems and applications; however, students may not be able to relate this back to the actual lesson. In the Integrated model, all STEM components are combined and is considered to be the best approach in the STEM field. The only negative of the Integrated model is the training needed for teachers since they have difficulty teaching with the method. In summary, the review paper by Widya et al. [16] provides a coherent understanding of the basics of STEM education for the 21st century. While schools may be lacking in adopting an integrative model due to the constraints of time, budget, and teachers' capacity, a summer program of this sort is free to explore innovative models.

Marx and Harris [17] examined the "No Child Left Behind (NCLB)" legislation and theorized how it would affect science education. In theory, science education is part of STEM education as the popular acronym is known to stand for, "Science, Technology, Engineering, and Math." The authors mention that science education is positively impacted by "inquiry-based instruction." In short, students build on the foundation of their prior knowledge with new information while understanding the scientific process of examining problems and formulating solutions. At the time, the authors had noted that NCLB may cause a deficit in science instruction alongside other subjects due to the increased focus in Math and Language Arts in grades 3-8 for which schools and teachers can not be blamed. It is also highlighted that meaningful science education with an emphasis on critical thinking towards real-world investigations may become exclusive to students in high-performing schools and districts. They emphasized the possibility of legislation, such as NCLB, causing great harm to science education. In theory, science education being a part of STEM education would signify that even STEM education would suffer. When learning of the possible impairments that could take place it is also important to learn about countermeasures that can help improve the quality of STEM education right from elementary level. This study shows a critical need to engage students in authentic and creative ways to show them the excitement of STE in STEM.

Pittinsky and Diamante [18] discussed the idea of incorporating the element of fun in STEM education. It is mentioned that often students are given a false sense of hope by being told the field is "easy," which can often lead to demotivation. It is also detailed that inspiration alone does not prepare students emotionally and academically to pursue a STEM major in the future due to the necessity of a strong foundation in math and science, alongside great willpower. At the time it was also measured that 60% of students intending to major in STEM end up switching majors or not graduating altogether. The authors go on to say that STEM actually requires curiosity and acknowledging the difficulties that may lie ahead, eliminating the possibility of endless and eternal fun. Motivators such as having a good job, becoming successful, and earning respect were also mentioned. Fundamentally, younger learners are convinced that if they choose to major in STEM in the future they can make it through, they can get through their classes and graduate with ease. This paper, however, highlights that the truth needs to be confronted. Students need to learn and accept that they can encounter failure; there can be a lack of "fun," or they may not succeed at all. This truth may be depressing, but it also features that it is important to understand when and how to teach students effectively so that they have the best chance possible to enjoy and grow in STEM. The summer MTRC Robotics camp seeks to provide a challenging experiential learning environment where students see that one does not have to sacrifice rigor while having fun.

Lesseig, et al. [19] in "Jumping on the STEM Bandwagon: How Middle Grade Students and Teachers Can Benefit from STEM Experiences," underline the importance of teaching STEM in middle school. First, they discuss that engagement in STEM-based curriculum can cause an increase in student interest towards STEM-related subjects. Furthermore, they talk about a "developmental uniqueness" at the middle school level due to intellectual and physical changes. The uniqueness can serve as an advantage, but also loading the students with enthusiasm and confusion. Theoretically, introducing students to STEM at this point can help them channel their energy and provide them with a safe space so they can learn and stay secure at the same time. This paper also elaborates that teachers often have outdated methods that do not ensure that students can connect problems back to concepts. They also reported on a unique professional development project called TESI - "Teachers Exploring STEM Integration" to help teachers co-learn with middle school students. TESI helped the educators take on a new role, thus granting them a new perspective of how STEM is perceived by students. To add on, it was also understood that classes such as "Engineering Design" could help low-performing students outshine their peers if given the opportunity. They summarize that STEM education could be made interesting by integrating engineering design in middle school curriculum.

Kong and Wang [20] emphasize the need and impact of nurturing interest-driven creators in robotics. They sought to apply the Interest-Driven Creator (IDC) theory by Chan et al. [21] to the development of a robotics education curriculum for elementary school students. While the IDC theory utilizes interest loop, creation loop, and habit loop, they focused on how interest loop, i.e., triggering interest, immersing interest, and extending interest, influences students' creation. To trigger interest, curiosity is gauged and then engaged. In a state of immersed interest, students become fully involved in their robotics projects and gain confidence in their abilities. Finally, in an extension of their interest, students see their accomplished task and how meaningful it has been to them, leading to further motivation. In their hypothesis, Kong and Wang add another step between immersion and extension, that is, of robot creation.

These aforementioned pieces of literature reveal that there are many intricate factors that affect STEM education. Interesting and innovative robotics curriculum can help prepare students for a future career in STEM. Education and familiarisation occurring concurrently helps flourish the students' confidence and enjoyment while tackling a difficult and complex subject. There are also a variety of arguments that can be made regarding the optimal time to teach students STEM, the benefits and detriments of introducing academic legislation, and telling the truth about STEM and its difficulty. While this leads to many unanswered questions, today STEM learning is at a crossroad further accentuated by the COVID-19 Pandemic where fear plagues proper instruction and a new era of online learning beckons.

3 Program Design and Implementation

While the MTRC Robotics camp in 2018 and 2019 was offered over a period of two weeks in person, in this paper our focus will be on the virtual versions of the program in 2020 and 2021, which consisted of a pre-camp week of self-driven and self-paced activities followed by two weeks of intense work for a total of three weeks. We shipped out robot kits to all the students a week before the beginning of the pre-camp week and assigned one coach to a group of 10 students. Coaches were engineering students from Stony Brook University selected based on their knowledge of mechanical design, electrical circuits, programming, robot design, and temperament while dealing with younger children. The coaches would organize workshops, answer questions that the students had, offer guidance from personal experiences, and communicate regularly with the students through a variety of mediums. Coaches were supervised by mechanical engineering professors and a program manager. At the very beginning, students were given a pre-camp survey that helped gauge their abilities, their outlook towards STEM, and potential career interests. Some of the questions were repeated in a post-camp survey.

3.1 Pre-Camp Week

Since the students in the program came from different grades with varied backgrounds, an extra week of activities before the formal beginning of the program allowed all students to reach a minimum level of knowledge and skills necessary to succeed in the program. During this pre-camp week, they were assigned daily tasks and had to submit a small presentation at the end of the day reporting on their progress. We also asked for daily feedback on the assigned tasks so that we could refine them for the future students. These tasks were designed as mini projects to be done independently so as to progressively build their confidence and to give them agency in how they approached the problems and solved them. While we assigned daily tasks and content to review, there were no synchronous sessions in the pre-camp week with coaches and instructors. We used Google Classroom for class management, task assignment, and communication with and among students. We sent each student a SnappyXO Advanced Robotics kit, which contains two hardware boxes consisting of structural parts and mechatronics components needed to build and program robots, MotionGen Pro software for motion design [22], and a robotics curriculum with lesson plans and projects for students. The curriculum was extracted from an undergraduate design innovation class created and taught by the first author at Stony Brook University. Table 1 shows the daily tasks assigned to students in the pre-camp week, while Fig. 1 shows a few students' creations.

Table 1: Pre-Camp Week Activities

Day	Tasks	Category
1	Design and build stable and dimensionally constrained structures to demonstrate knowledge of connectors and structural parts in the SnappyXO robotics kit	Mechanical Design
2	Design and build circuits using breadboard, LEDs, momentary switches, resistors, and DC motors to demonstrate basic knowledge of circuits	Electronics and Electrical Circuits
3	Design and build electro-mechanical devices such as a motorized fan, a strobe alarm, or a wheeled car with moving parts driven by an electrical power source	Mechatronics
4	Design and build four-bar mechanisms using MotionGen Pro to demonstrate an understanding of mechanisms to create specific motions	Mechanical Design
5 and 6	Design and build programmable electronics and simple robots, such as automatic night lamp, controllable wipers, obstacle avoiding wheeled robot	Computational Thinking and Robot Design

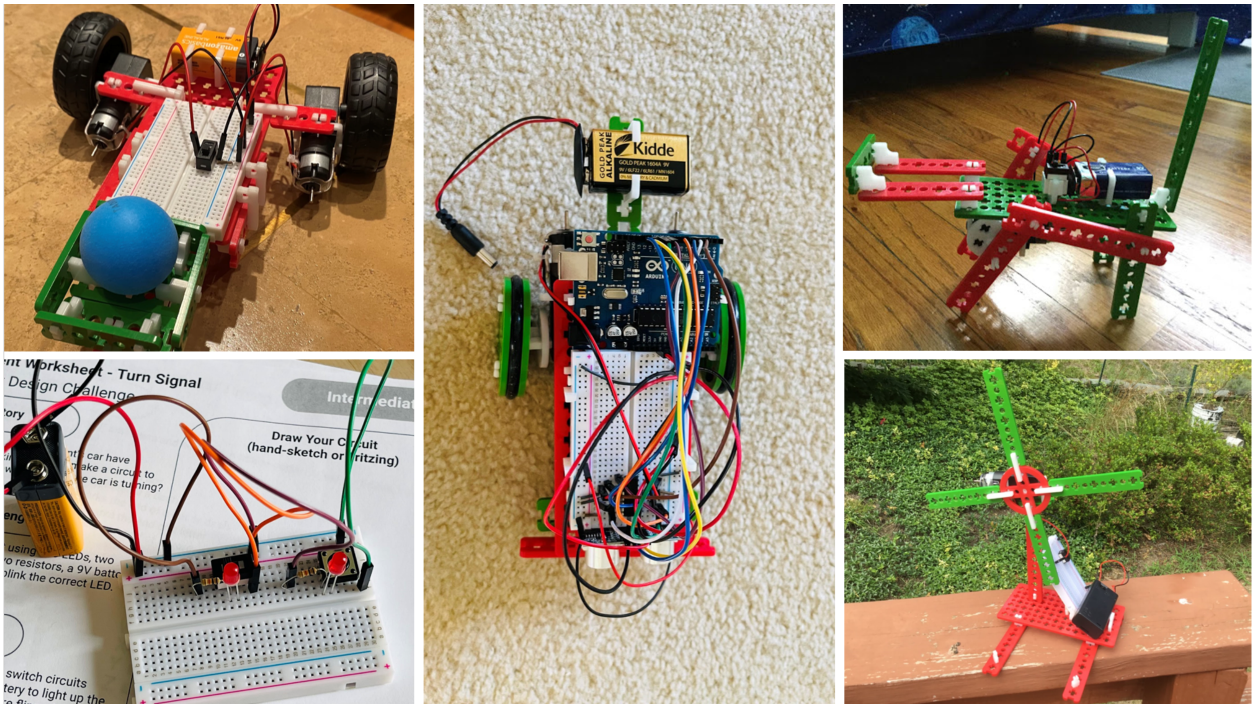

Figure 1: Students’ Creations from the Pre-Camp week

3.2 Camp Weeks

As the first week of the pre-camp ended, students had completed most of the activities independently, without much help from coaches. The intent behind independence was to bring out creativity and innovative ideas from the students and enable them to learn on their own. However, coaches continued to monitor the Google classroom stream and answered any questions that arose. At this point, students had become familiar with the basic content of the curriculum and were prepared for the next step. At week’s end students were organized into pairs based on individual student’s preference and their skill and grade level. The partners were organized so teammates could communicate effectively and comfortably with each other. For example, we paired a 7th grader with another student who was no higher than 9th grade. Similarly, a 10th grader was paired with an 11th or 12th grader. This ensured that students in each team could feel comfortable speaking to their partner and also minimized variation in skills and knowledge. Student teams were also assigned a specific coach and were directed to work proactively alongside their coach.

The next two weeks of the camp were split in the first week focusing on the content discussion and assigned activities and the second week spent on their capstone design project in teams of two students. In the morning sessions of the first week, coaches would present workshops on engineering design, electronics circuit, electrical machines, and microcontroller programming using Arduino. The second half of the day was spent on students working on their assigned tasks, but could reach their coaches and team mates using Discord and ask questions. They also used Discord to communicate with their classmates, which helped build a casual and social, but safe interaction environment.

The second week of the camp built on top of the activities of the pre-camp. However, students who had not completed the last activity of the pre-camp, were given an opportunity to work with their coaches to complete it. The last activity was a critical one since it brought together their knowledge of mechanical design, motor control using an H-bridge IC and breadboard, and Arduino programming to design and program an obstacle avoiding wheeled robot using an ultrasonic sensor. Students who had completed this basic wheeled robot were asked to change the programming to create different behaviors in their robot. This reinforced the idea of Behavior-based Robotics made popular by the noted MIT Scientist Rodney Brooks [23]. The next three days in the second week focused on the manipulation and control of robots, which included programming a servo-driven robotic arm and controlling its motion using ArduinoBlue app [24] over Bluetooth. The ArduinoBlue app allows students to design their own simple user interface in the app to control different aspects of their robot using an iOS or Android device. Table 2 summarizes the activities of the second week and the Fig. 2 shows a few students' work.

Table 2: Second Week Activities

Day	Tasks	Category
1	Complete an autonomous two-wheeled robot with ultrasonic sensor	Locomotion with Sensing
2	Remote Control of two-wheeled robot using ArduinoBlue over Bluetooth	Remote Control
3	Add a robot arm using servo to pick up an object	Manipulation
4	Control robot arm and wheeled robot using ArduinoBlue	Remote Control
5	Problem identification and Capstone Design Proposal by Students	Capstone design project

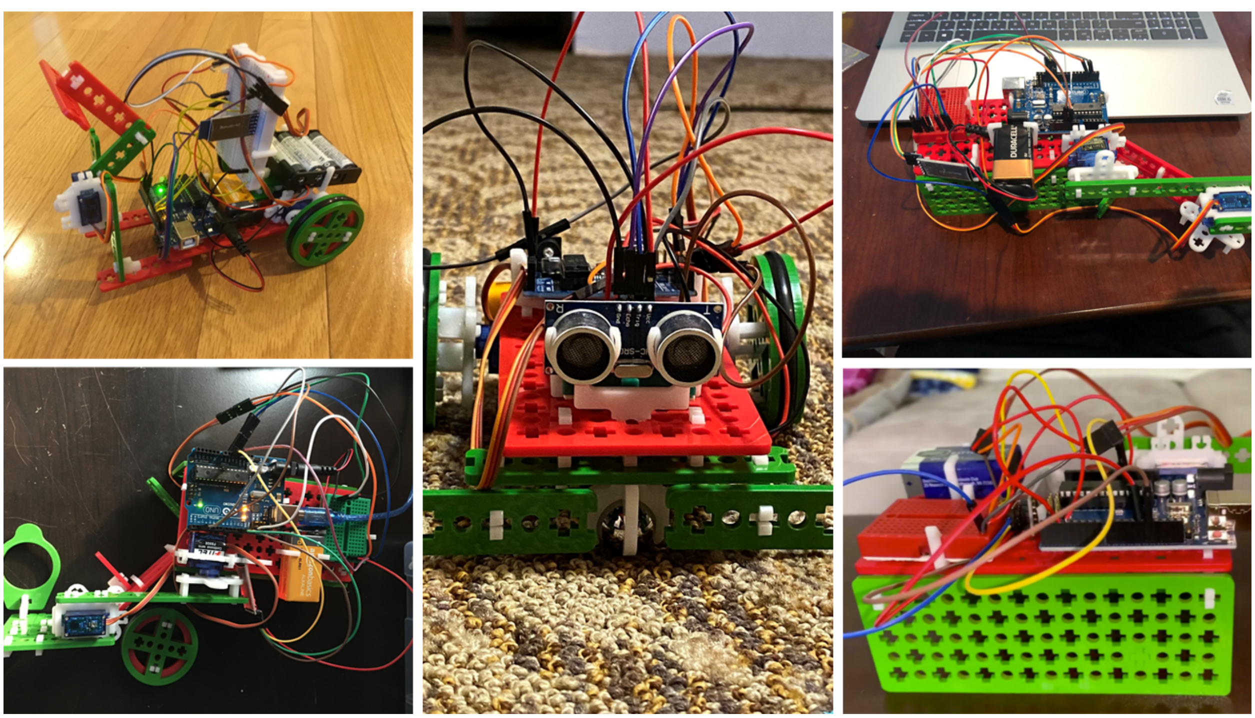

Figure 2: Students' creations from the second week of the camp

As the second week ended, student teams were asked to identify a problem with a potential robotic solution and submit a proposal to the teaching team. In 2020, the theme was a robot that could help solve problems created by the COVID-19 pandemic, and in 2021 the theme was a robot that would promote social activities. By focusing on the theme and incorporating interesting locomotion and manipulation mechanisms in their robots, students completed their capstone projects in the last week. While students brainstormed ideas, instructors would listen in and provide feedback, and eventually provide their approval when convinced that the students could complete the project. Essentially, instructors would also serve as regulators in the brainstorming process to ensure that the student could complete their project at their skill level, while also maintaining individuality of their robots with complexity suitable for their skill-level. The third and final week of the camp was spent on students independently working with their teammates to design, develop, build, program, and test their project prototypes. After completing their projects, they prepared and recorded a presentation for the final demo day, which was attended by the program director, teaching team, students and their family and friends; see Fig. 3 for a few teams' final product. Students also filled out a post-camp survey to provide their thoughts and feedback about the structure of the camp and the instructions they received.

Figure 3: A few teams' final prototype from 2021 Summer Camp

4 Data, Assessment, and Feedback

While the MTRC Robotics camp was offered in person in 2018 and 2019, in 2020 and 2021, the program was offered virtually only. In 2020, students were given a post-camp survey only, while in 2021, students were given both a pre- and a post-camp survey. To keep comparisons fair, in this section, we only present the pre- and post-camp data and analysis from 2021. The survey contained both quantitative and qualitative questions on a range of topics, such as their interest in STEM fields, prior participation in STEM camps, their confidence level in four primary engineering topics, viz Engineering design, robotics, electronics, and computer programming, and their choice of engineering major for college. The post-camp survey repeated relevant questions and also asked them of their opinion on the effectiveness of the camp in improving their interest in STEM careers and their proficiency in the aforementioned engineering topics.

Figures 4 and 5 show the age, gender, grade, and ethnicity range of the students (N=36) who completed the post-camp survey. While a total of 60 students participated in the program, only 36 students completed the post-camp survey and only 24 completed the pre-camp survey. In future, we plan to make surveys mandatory as part of program participation.

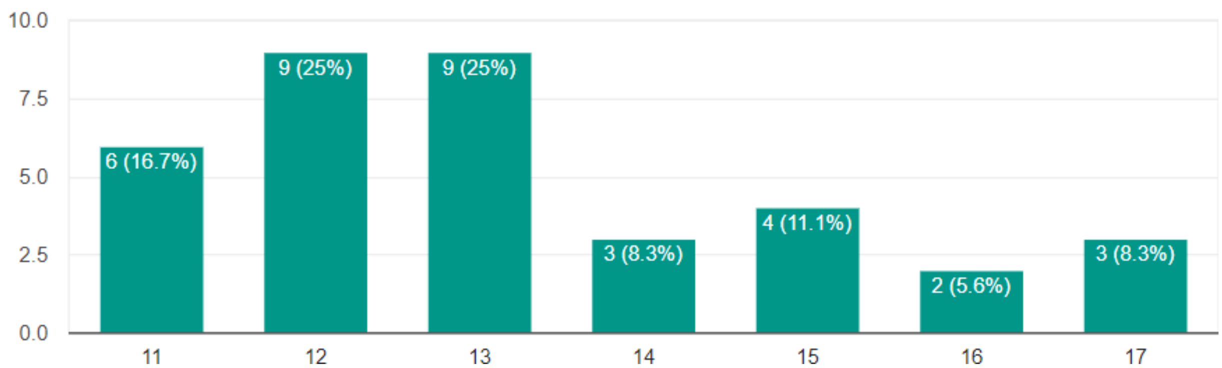

Figure 4: Age range of Students; N=36

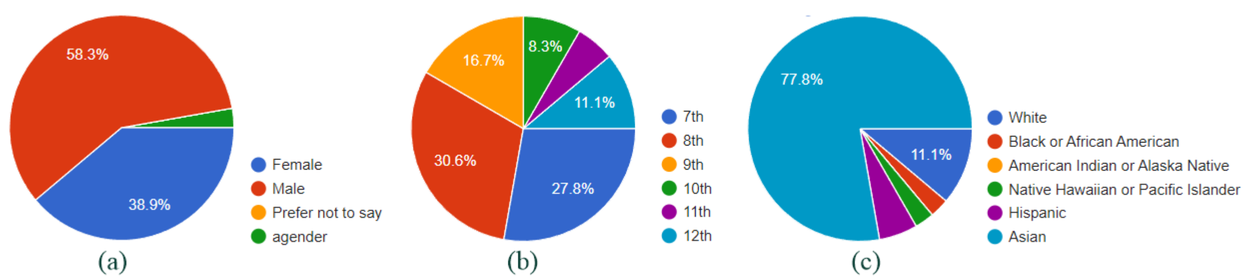

Figure 5: Demographic information of Students; N=36 (a) Gender, (b) School Grade, (c) Ethnicity

As the Fig. 4 shows, a majority of students were young teens. These students, unlike the older students, may not have had much exposure to STEM in school and might also have lacked any significant exposure to the four engineering topics. Of all the students who took the pre-camp survey (N=24), 100% of them said strongly agree (66.7%) or somewhat agree (33.3%) on a five-point Likert scale to the assertion, “I am interested in career that use science, math, technology, or engineering.” In response to the question, “I am able to get good grades in Science and Math classes.”, all of them asserted “strongly agree” (91.7%) or “somewhat agree” (8.3%). Figure 6 shows that most students’ had participated in at least one other STEM camp and had carried out diverse activities in the last two years. These responses indicate a high degree of interest in STEM fields and capacity and preparedness to tackle challenges beyond the classroom. This is reflective of the self-selection bias that one often encounters in summer programs and after-school activities like these.

At the end of the program, students completed a post-camp survey, which provided insights on students’ learning in the flipped-learning format and their attitudinal shift to their career choices. In particular, we asked following questions:

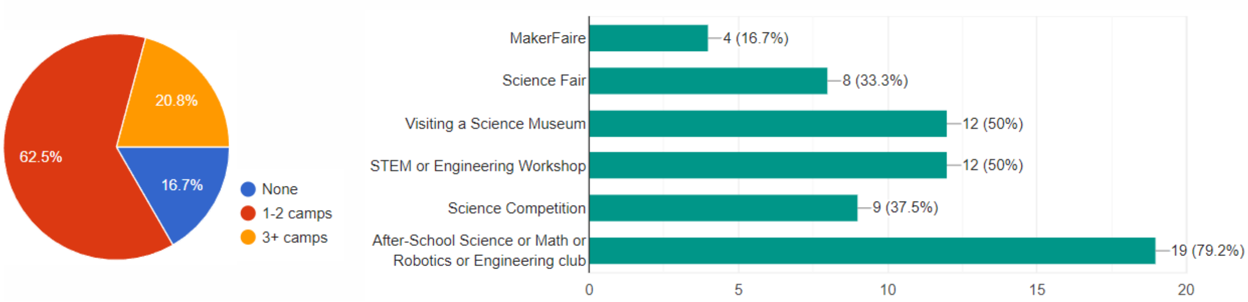

Figure 6: Left: Number of prior STEM camps participation, Right: STEM activities pursued in the last two years (N=24)

1. Did the students change if and or which STEM major the students wanted to pursue in college?
2. Was there a change in how the students viewed their skill levels, abilities, and confidence?
3. How did students reflect on their abilities before camp started, and were there significant changes?
4. How do the students feel about their STEM classes now; are they more relatable?
5. Do the students feel like they have a greater interest in STEM now?
6. Was the camp enjoyable for the students and if the teaching team did a good job?

Figure 7 shows that before the camp began, a majority of the students (33.3%) wanted to pursue Computer Science (CS) as their major in college and the next two major choices were Mechanical Engineering (25%) and Electrical and Electronics Engineering (12.5%). After the camp was over, Mechanical Engineering (ME) became the most preferred major (36.1%) followed by Computer Science (30.6%) and Electrical and Electronics Engineering-EE (19.4%). What is interesting to note in this figure is that while students wanting to major in CS reduced by a small percentage, both ME and EE became more preferred. Before the camp, the CS, EE, and ME majors constituted of 70.8%, and at the end of the camp, this cumulative percent was 86.1%, which shows that the preference for ME and EE did not come at the expense of the CS, but was drawn from other disciplines. This can be explained by the fact that students in the camp pursued a balanced set of activities, which equally emphasized three important aspects of robotics, i.e., mechanical design, electronics, and computer programming.

The choice of college major is highly dependent on students' own motivation, capacity, friends' and family influence, and role models [25, 26, **?**]. An early exposure to topics which reflect upon a discipline and students' confidence in mastering those topics could also play a role in deciding a major. The survey asked self-efficacy questions in the pre-camp survey and then repeated them in the post-camp survey. The post-camp survey also asked them to reflect on their knowledge of the topics *before* the camp. Students can judge their abilities only to the extent that they are exposed to a topic since they do not know the threshold for a learning outcome. Therefore, repeating those questions in the post-camp revealed some insights.

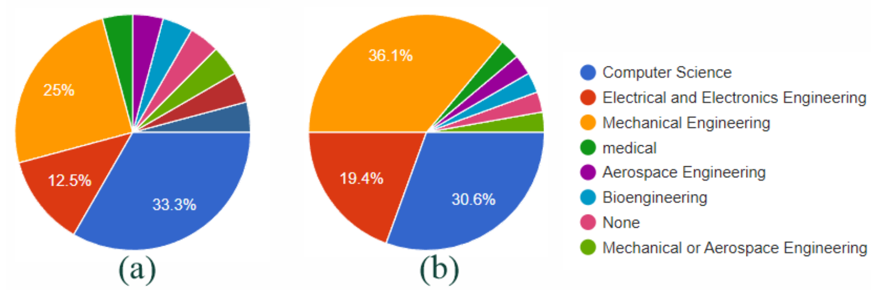

Figure 7: (a) Choice of major pre-camp survey (N=24), (b) Choice of major post-camp survey (N=36)

In the two surveys, students were asked to rate their skills on a scale of 1-10 in response to the following four prompts:

1. How confident are you about designing, building, and programming robots?
2. How would you rate your circuits and electronics knowledge?
3. How would you rate your programming knowledge?
4. How would you rate your Engineering design knowledge and build skills?

Figure 8 shows a comparative chart of the average of students' responses. Interestingly, when asked to reflect back on their knowledge and abilities before the camp began, students lowered their score. This is an indication that they made a correction to their self-efficacy based on what they learnt in the camp. For example, in the pre-camp survey, students' average score for the prompt on their confidence in designing, building, and programming robots was 7.33, it was corrected to 5.00 when asked to reflect back on their knowledge before the camp. Regardless, while taking the pre-camp survey, on average the students believed they could do a good job on the activities and projects assigned to them during camp. The pre-camp scores show that students were most confident about their skills in robot and engineering design, then programming, and the least in electronics. This data helped determine the areas where the students might face the most challenges.

Post-camp survey results clearly show that the students were more confident in tackling the challenges of four primary engineering topics drawn from CS, EE, and ME. The maximum gain was made on their knowledge of circuits and electronics.

While students rated their skill levels they also provided feedback on what they intended to do with the knowledge they would receive in the camp. Students were given the following prompt:*"What do you expect to learn from this camp and how will you use what you learn in future?"*. This prompt also helped gain insight on why the students were pursuing knowledge in a STEM field. One student answered, "I will use this camp to help me with my hardware skills for when I create my own Computer Science/Hardware Business." Another student answered, "To learn new stuff about robotics like programming, so I could use it when I join robotics in high school. Which could lead to my future career." Yet another student said, "How to build different gadgets/structures that can help me in everyday life. I want to be able to build something and program it to help me with my job in the future."

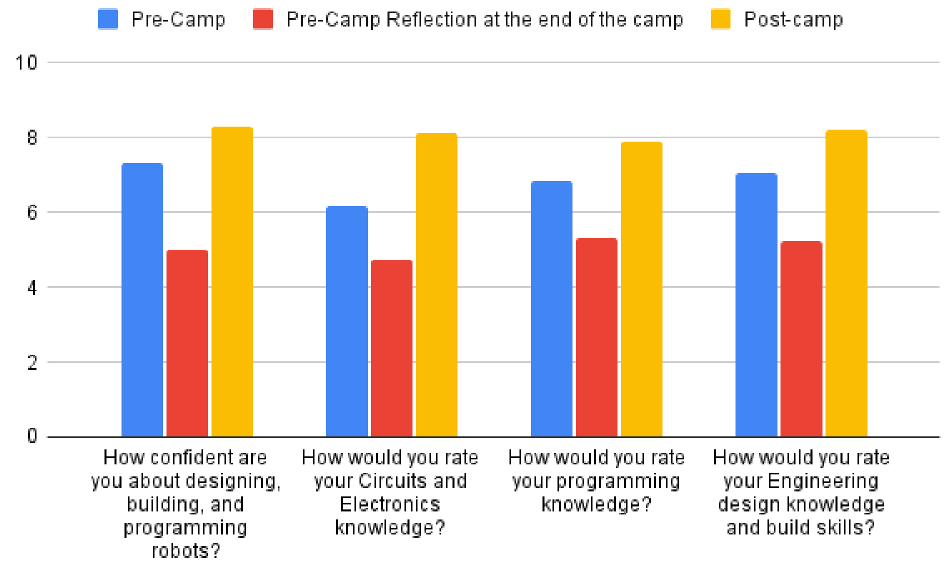

Figure 8: Pre-camp (N=24) and post-camp (N=36) survey average scores of students' self-perceived abilities in four primary engineering topics on a scale of 1-10

The post-camp survey also asked students to rate 1) if their interest in a STEM field increased, and 2) if the camp made them feel that some of their classes were more relevant and interesting on a five-point Likert scale. The results are shown in Fig. 9. A total of 97.3% students agreed or strongly agreed that their interest in a STEM field increased as a result of the camp (average 4.53), while 69.5% agreed or strongly agreed that their classes would feel more relevant now (average 3.97). All but one student said that they had fun in the camp and all of them found topics interesting and would recommend this camp. The only exceptional student said that she was unsure if she had fun.

We also asked students if and what was most valuable about this camp? Some of the answers that we received were:

1. The most valuable skill I attained from this camp was adapting to Engineering-based thinking for practical uses, such as designing a mechanism or constructing a sturdy chassis for a robot.

2. I think what was most valuable about this camp was that I learned how to be innovative in both building and programming. Even though we did not have a lot of time for the Capstone Project, me and my partner were able to come up with a cool idea and we were able to execute the idea on time.

3. Independence because with the way the camp was structured, i (*sic*) got to take charge of my own creations and rely on myself to push forward.

4. It helped me decide on a major I wanted to pursue. I was deciding between either cybersecurity or electrical engineering as my major, but I've decided to pursue electrical engineering, since this program helped me get a better grasp of what that would entail

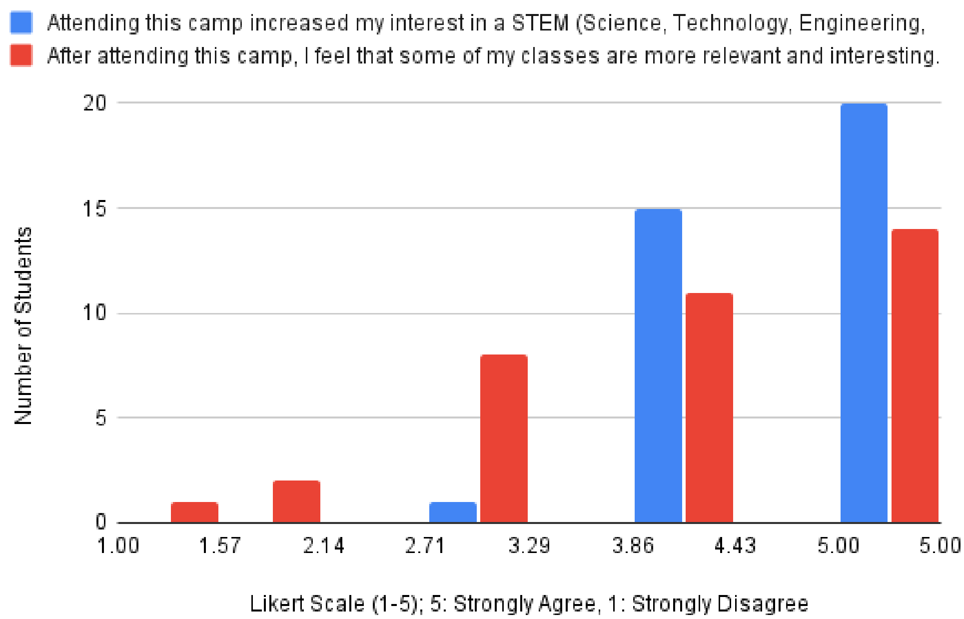

Figure 9: Post-camp rating of class relevance and increased interest in a STEM field

5. I came into this camp with zero experience in coding, circuits, and robot design. I learned so much within three weeks of working independently and with a team from morning till night. I am leaving here with new friends, more confidence in myself, and a robot that I can be proud of. The overall experience that you undergo throughout this camp is very valuable. I would like to thank MTRC for arranging this. I cannot even describe how much fun I had!

6. I think the most valuable part of this camp was how it taught us so many aspects of robotics, allowing us to find what we like best. It taught us computer science, electrical engineering, and mechanical engineering. I, for example, already had a passion for computer science and programming before the camp started, but after the camp I realized how fun electrical engineering could be.

7. I feel like the most valuable thing about the camp was the inclusion of design with robotics. Most classes nowadays only focus on the programming aspect of robotics. For instance, in one of my freshmen robotics classes we had templates to use to build and we would code ourselves. The inclusion of the design process made all the difference and was super fun to do.

8. The camp really opened my eyes to the possibility of doing robotics in the future. Before attending the camp, I had no skills in robotics and so I never considered pursuing robotics in my high school. However, after completing the camp, I feel a lot more confident in my design, coding and electronics knowledge and I will certainly do more robotics projects in the future.

9. To me the most valuable thing about this camp was the knowledge that I got out of it. I had been bored all summer prior to this opportunity and this camp really granted me knowledge

in ways I could enjoy, and hadn't done for the last 2 years due to the pandemic. In these last 2 years of the pandemic I missed out on the hands on (*sic*) aspect of engineering, and this camp really helped fill that gap that was missing for me.

10. The most valuable things about this camp is that it is taught in a whole different way that the occasional teacher would teacher (*sic*) his/her students and how the instructors give you a challenging way of practicing vs the typical school teacher giving things that can easily be solved by students.

There were also suggestions made by students for improvement to the program, which included increasing contact time with coaches during the pre-camp week, providing more coding training, allowing more time to complete activities or eliminating some of them, providing videos for learning content instead of long technical documents, enabling students to connect with each other socially outside program hours, and equipping the robotics kit with more robust and better parts.

5 Conclusions

The major conclusions that can be drawn from this study are that online robotics camps are technically feasible, accessible, and effective in engaging middle-to-high school students. During the COVID-19 pandemic, the value of hands-on work and experiential learning became glaringly obvious. The MTRC Program at Stony Brook University utilized an innovative virtual-physical robotics teaching platform to deliver a three-week long summer robotics camp, which included topics from several key engineering disciplines, viz mechanical design, practical electronics, and computational thinking. The 2021 version of the camp had 60 7th-12th grade students enrolled from the entire NY-state. These students received their hardware robotics kit in advance of the camp and due to the affordability of these kits, they were allowed to keep them at the end of the program. Due to the virtual nature of the program, students from far flung regions of the state could participate in this program, hitherto not possible. The pre- and post-camp surveys showed that students developed significantly better understanding of key robotics concepts, helped them make suitable decisions about their choice of college majors, showed them that robotics is much more than coding, and helped prepare them to take more advanced courses in high-school. The future plans are to continue offering this program in a completely virtual format for students from across the state as well as offer an in-person program for the local students.

Disclaimer

The SnappyXO Educational Robotics kit consisting of the patented hardware was invented by the first author in his Computer-Aided Design and Innovation lab at Stony Brook University (SBU) for his Freshman Design Innovation class. The MotionGen Pro software is based on an NSF funded award (#1563413) to the first author as the PI. This product is now being commercialized by a SBU spin-off co-founded by the first author. The follow-on research and development of the SnappyXO Design has been supported by an NSF I-Corps award (#1823736) to SBU and STTR Phase and Phase 2 awards (awards #2126882) to the startup. All opinions and conclusions presented in this paper are those of authors only and not of funding agencies.

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