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Cultivating Robotic Professionals: A Learning-Practice-Service Educational Framework

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Abstract

Robotics, an interdisciplinary field spanning various science, technology, engineering, and mathematics (STEM) disciplines, is recognized as a transformative force shaping our daily lives. With its broad popularity among children and teenagers, robotics serves as a fertile ground for cultivating future professionals in science and engineering. Introducing structured robotics education to young learners at an early age can attract highly promising students to STEM fields. However, formal robotics education typically begins in college, by which time many students have already chosen their majors. To bridge this gap, robotic competitions have emerged as crucial incubators for nurturing future scientists and engineers.

This study proposes a novel Learning-Practice-Service (LPS) framework for robotics education tailored to 7th-12th graders, with three independent and complementary components: Learning, Practice, and Service. The LPS framework encompasses comprehensive learning and practice activities, combining academic challenges with hands-on experiences, and covering the entire robotics education process from problem statement to real world operation of robots in competitions. It fosters skills across various STEM disciplines, integrates technical and non-technical training, and cultivates leadership and community engagement skills. Implemented through participation in internationally recognized team-based robotics competitions over three years (2020-2023), the LPS framework has been further extended to include training sessions in three summer camps for 2nd - 8th graders and two extracurricular clubs for 6th-8th graders in regular school semesters.

The framework has been assessed using data collected from more than 1,900 learning-practice-service hours, in which students solved varied real world engineering problems and tested their robots at competitions, presented their learning outcomes in judge rooms and conferences, and conducted a range of service projects involving local, national, and international partners. The collected data encompasses team achievements in robotic competitions over three years, individual student accomplishments, and the effects of services delivered via the LPS framework. The assessment of the LPS framework's impact relied on service hours, outreach scales, and feedback collected during the summer camps.

The analysis confirmed the framework's effectiveness in enhancing students' technical and soft skills, sustaining their interest in STEM, improving team performances, and fostering an inclusive community for collaboration. The LPS framework offers students flexibility in developing their skill sets and has been proven to be sustainable, transformable, and scalable for integration into K-12th engineering curriculum and extracurricular programs.

Introduction

Robotics has been identified as an interdisciplinary field encompassing electrical components, computer vision, mechanics, cognitive science, and artificial intelligence [1-5]. Innovation in robotics has become a transformative force to reshape the way we live, work, and interact. From enhancing road safety to revolutionizing healthcare, robotics offers novel solutions to a diverse array of challenges and has evolved from an idea in science fiction to become a reality integral to the human experience in the twenty-first century. This paradigm shift underscores the importance of preparing young minds for contemporary life and future innovations through the exploration of robotics as robotics is one of the most widespread interests among children and teenagers. These facts further contribute to an uptrend of introducing robotics into STEM (Science, Technology, Engineering, and Mathematics) curricula at an early age, aiming to cultivate robotic professionals among youth and prepare them for the demands of future technologies [6-11].

Building robots requires students to apply classroom knowledge to hands-on projects, bridges the gap between theoretical learning and real-world applications, and fosters skills in critical thinking, problem-solving, coding, math, and science. A recent comprehensive review of 147 studies focusing on K-12 robotics education confirmed the general benefits of educational robots and specifically categorized the benefits into four themes: "enhancing students' learning and transferring skills, increasing creativity and motivation, enhancing diversity and broadening participation, and improving teachers' professional development" [12]. Despite notable advancements in robotics education, there are areas where improvements could be made, suggesting opportunities for further efforts and enhancements. Some prior studies emphasized the importance of "pedagogical modules" [13] in robotics education, while "the majority of exist studies lacked an experimental or quasi-experimental design" [12]. Instead, many robotics education studies were conducted in short term, irregular learning settings such as after school programs [14, 15] and summer camps [16-18] rather than formal learning settings such as classrooms. The prevalence in informal settings may limit their applicability for K-12 curriculum development. Furthermore, fewer studies discussed diversity and broadening participation although demographic, social, and gender and ethnic diversity in STEM has proven to be crucial to promoting social justice and fostering scientific innovations.

This study proposed a novel Learning-Practice-Service (LPS) educational framework on robotics, which has been developed for 7th-12th graders, implemented by forming a robotic team and practiced for robot development and operation through an international robotics competition platform during a span of three years (2020-2023). The proposed LPS educational framework seeks to provide students a well-structured learning cycle, academically challenging and sustainable hands-on experiences with practices, and a service-based learning component. Learning in the LPS framework is comprehensive 1) in its holistic coverage of the robotic education process such as design, build, manufacture, integration, optimization, and testing, 2) in its encompassing technical learning on mechanics, electronics, and programming 3) in its integration of technical and non-technical learning such as communication, business, and teamwork, and 4) in its fostering leadership and community engagement through growing students as not only learners but also knowledge transmitters and producers. Student participants also have the flexibility of identifying areas of special interests and strengths to develop their skill sets and prepare for future academic and professional development.

The LPS educational framework has been implemented through the formation of a team participating in an international robotics competition, FIRST Tech Challenge (FTC), and assessed using data collected from more than 1,900 learning, practice, and service hours from 2020 to 2023. Rather than a random one-time passion project, the LPS framework emphasizes a consistent, ongoing pattern of learning beyond the classroom, characterized by direct, hands-on experiences. Its student outcomes have been examined through challenging participants with real world authentic engineering problems, and evaluating their work based on explicitly articulated criteria [19].

This study is also distinctive in its focus on a group of high school student participants at one of the largest school districts in one of the most formative years (7th-12th grade) of their academic career. Sustainability of the proposed educational framework has been a central consideration as we not only aim to build this specific group of children holistically for success but also aim to use this LPS framework to catalyze STEM interests and proliferate many more successful teams. Additionally, the LPS framework is intended to be transformable and scalable for K-12 educators to integrate into their engineering curriculum and to launch school team/interest clubs to enrich their extracurricular activities.

Methods

Objectives of the LPS Educational Framework

The LPS educational framework seeks to achieve three objectives: 1) empower K-12 students to excel in the fields of STEM with structured learning and practices; 2) foster students' leadership and self-esteem in building more inclusive and connected learning communities by serving the community; 3) enhance students' interest and engagement in STEM through targeted learning and service-based learning that further boosts their STEM aspiration. The three components: learning, practice, and service in the framework are independent and complementary to each other to achieve the objectives of the LPS framework.

The LPS framework was designed for, implemented upon, and assessed through students participating in FTC style competitions. Assessment of this framework considers various artifacts of students' individual achievements including their technical and non-technical skills, professional certificates, and awards, team achievements such as competition results, training effects of 130 2^{nd} - 8th students with the LPS framework through summer camps and extracurricular clubs, and outreach impacts, and team sustainability plan.

Selection of the Implementation Platform: FIRST FTC program

Engineering competitions have been instrumental in attracting students to STEM fields, providing a nurturing environment for future engineers and scientists. These competitions are known for their prestigious history, strong reputations, and well-organized structures. While numerous national and international robotics competitions exist, we chose to focus our research on the FTC platform for three specific reasons.1) Established in 1989, FTC is a world-class platform with over 70,000 participating students in 50 countries and regions. It remains strong despite the challenges of the pandemic, with the number of participants exceeding the pre-pandemic number in 2023. FTC engages students with STEM concepts, offering them unique hands-on experiences through project-based learning, which serves as an ideal “Practice” component in the proposed LPS framework. 2) The judge room presentation component of the FTC competitions requires students to document, reflect, and learn from their experiences and this helps us gather necessary data to evaluate the design, implementation, and results of the LPS framework. 3) Compared with other educational robotics platforms such as VEX [20], B.E.S.T [21], and World Robot Olympiad (WRO) [22], FTC’s motto of Gracious Professionalism more accurately addresses the service component of the LPS framework in its emphasis on building teams and communities while striving for innovation.

Formation of the Student Group

The initial team, FTC team #16458 (TechnoWizards) comprised 8 students, including one 9th graders and seven 8th graders within the same district. This team was formed in response to the 2020 FTC team enrollment call and continued their participation in the 2021- 2022 season. In the subsequent 2022-2023 season, one team member joined the FIRST Robotic Challenge (FRC), an affiliated program with FTC and a new member (an 8th grader) joined after completing the application, evaluation, and team interview process. Throughout the ongoing 2023 - 2024 season, the team expanded further with the addition of 3 new members from 7th, 8th, and 11th grades, respectively. In total, 13 students, including 3 girls, have been trained with the LPS framework from 2020 to 2023.

Implementation of LPS Cycle in Team Sustainability

The implementation of the LPS cycle in team management was geared towards sustaining team spirit. At the beginning of each school year, team members collaboratively defined a team goal, which was then broken down into various tasks. Each task was outlined, including objectives, anticipated milestones, and a deadline for completion. One team member assumes the position of a task manager, with another team member serving as the assistant. The yearly team objectives and segmented tasks were typically derived from the FTC game manuals, encompassing detailed technical specifications and outreach/impact requirements from FTC competitions.

Initial members learned task separation in the first year, practiced task separation in the following years, and served to train new members for this LPS cycle to fertilize team sustainability and nurture a cohesive team spirit. Every team member underwent training and was encouraged to take on the responsibilities of a task manager, adhering to the LPS cycle to successfully execute their assigned tasks upon joining the team. This LPS cycle formed the backbone of team building and collaborative efforts.

Task-driven LPS Cycle

Every technical or outreach task was performed by team members following an LPS cycle as shown in Figure 1. An LPS cycle started with defining the task objective, assessing the existing capabilities, pinpointing new knowledge or skills to acquire, securing mentors for the identified areas, engaging in learning sessions, applying acquired knowledge through practice, evaluating the outcomes of learning and practice, conducting necessary follow-up sessions for enhanced learning and practice, and ultimately, contributing to the community by disseminating the gained knowledge and skills within the team, FTC community, or a broader public audience.

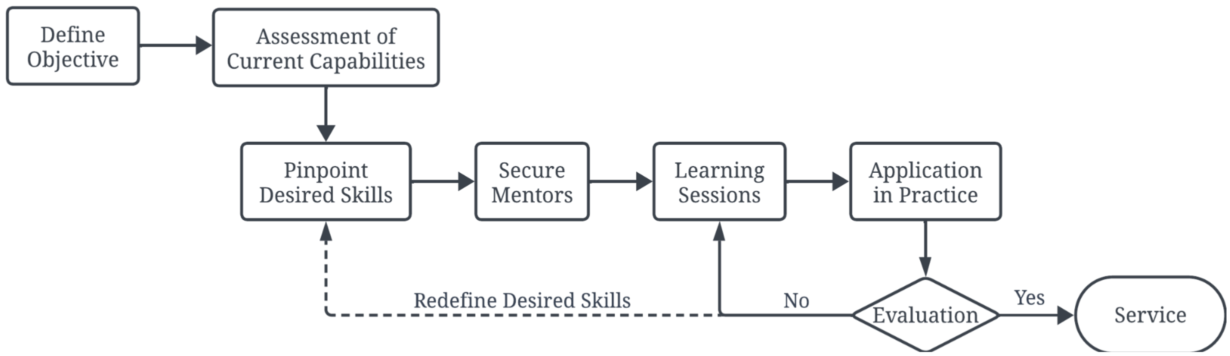

Figure 1. The Learning-Practice-Service Cycle was depicted with detailed steps. Upon achieving the predefined objective, follow-up service will be conducted. Alternatively, if the objective is not met, iterations may be required to pinpoint additional skills and restructure learning sessions in order to achieve the predefined objective during the implementation process.

Scope of Learning Sessions

The selection of learning topics was determined by two primary factors: 1) the outcomes of a team survey conducted at the beginning of the school year, where members expressed their desired roles within the team and identified the skills they aimed to develop; and 2) an examination of the game manual, released each September, which outlines the distinct skill sets needed for the particular challenges presented in the game for that year.

The learning sessions cover a broad spectrum, including both technical aspects related to robot development and non-technical skills essential for communication, networking, community service, and conflict resolution. Technical sessions involve proficiency in computer-aided design (CAD) for mechanical components, programming in Java, and utilizing various programming libraries like OpenCV and Roadrunner. Non-technical sessions encompass tasks like creating event reports, maintaining an engineering notebook, engaging in business development, honing public speaking and presentation abilities, and developing socio-cognitive soft skills such as confidence, teamwork, time management, and organization. Typically conducted before the FTC competition season, these learning sessions establish a robust foundation, preparing students for focused and intensive work when the season kicks off in September each year.

Connecting with Professionals for Learning Sessions

Once the topics were determined, the team proactively sought mentors in the respective fields using various channels such as Google Scholars, university and research institute websites, social media platforms, and connections within the networks of coaches, teachers, and family. An initial contact with potential mentors was established through email, LinkedIn, or Instagram, and collaborative efforts were made to schedule either online or in-person training sessions. Most of the training sessions were recorded and broadcasted through YouTube Channels and could be reused to train new members. Free online resources for special training such as CAD were also available from the developers. A list of categorized training materials was documented and shared through social media.

Following the learning sessions, the team maintained regular communication with the mentors, sharing the impact of their expertise on the team and providing updates on the team's future plans. Throughout the year, mentors received an average of three updates from the team, including a hand-written holiday card in December every year.

Practice of Technical Knowledge and Skills from Learning Sessions

The LPS framework runs yearlong regularly. Most technical learning sessions were performed bi-weekly in the summer with practice sessions right after the learning sessions to enhance the understanding of the knowledge and skills. Throughout the 5-8 months of the competition season starting in September, the team met regularly, dedicating about 5 hours per week, with additional workdays during holidays and school breaks. Most of the meetings during the competition season was allocated for students to deepen their knowledge and skills through hands-on practices, involving activities such as robot design, CAD and Computer Numerical Control (CNC) machining, wiring, programming, and fine-tuning of parameters to achieve the specifications for an authentic robot design.

The team captain provided an agenda before the regular meetings, and each meeting started with a 20-minute discussion on individual task progress, potential challenges, and proposed solutions, followed by the identification of follow-up tasks. An engineering notebook was established to document the progress, technical details, for every meeting.

Practice of Non-Technical Knowledge and Skills from Learning Sessions

The team's business manager oversaw fundraising activities and delegated a team member to engage and follow up with potential donors. Communication templates, including initial contact, follow-up, and appreciation letters, were developed for team members to use. A team member documented a report for each team event, capturing event objectives, activities, attendee numbers, volunteer/service hours dedicated to event preparation, event photos, outcomes, and follow-up arrangements. Team members took turns writing event reports.

For judge room presentations and interviews, the team collaborated on organizing event reports, refining engineering notebooks, evaluating business outcomes, and crafting presentations. Annually, a 15-page portfolio was created in early January and continuously updated throughout the competition season. These diverse activities presented ample opportunities for team members to hone their non-technical skills.

Serving the Community

Sample service activities include peer tutoring for team members, mentoring and assisting other local FIRST teams, hosting robotic summer camps for 2^{nd} - 8th graders, organizing extracurricular clubs at schools for 6th-8th graders, disseminating knowledge and skills through annual podcasts, presenting at regional FTC kick-off meetings, showcasing robots at local, regional, and international STEM or non-STEM events, advocating for the significance of STEM education through legislation, creating content for YouTube channels and social media, and organizing regional FTC conferences for teams to exchange experiences.

The summer camps offered free and prioritized admission to economically disadvantaged students from the community. The team also recruited at Title I high schools and hosted a presentation and onsite visit for students in an under-resourced high school. Engaging in community service not only enhanced the students' involvement in STEM with a clear identity and heightened self-esteem but also nurtured interest in robotics within the non-STEM community. This further contributed to building a more inclusive community for robotic education, ultimately strengthening the sustainability of the team and the LPS framework.

Transformability and Scalability of the LPS framework

Although the LPS framework was initially designed and implemented for a small student group, we explored its transformability to larger student cohorts by implementing the LPS framework in three summer camps for the local community and two extracurricular robotics clubs at a middle school. Each summer camp accommodated 20 students ranging from 2nd - 8th grades, while two extracurricular clubs involved 30 and 40 students in grades 6-8, respectively. The summer camps provided 25 hours of learning, practice, and service sessions, and the clubs featured a total of 22 hours dedicated to learning, practice, and service activities. Students enrolled in the summer camps acquired skills through lectures, followed by practice sessions in small groups of four children. Each group collaboratively designed their own logo and slogan and worked on a hardware set from the beginning of the summer camp. The summer camps concluded with a competition among five groups, which were evaluated on Design, Innovation, Inspire, Motivation, and Team Spirit. Specifically, Inspire, Motivations, and Team Spirit awards encouraged young students to help, teach, and collaborate with each other as a service to the summer camp. Our team members served as tutors for both the summer camps and the extracurricular clubs, working side by side with campers throughout. At the end of each summer camp, feedback on the outcomes was collected. The extracurricular club was run on a similar pattern as summer camps, applying the LPS framework to middle school students.

While hosting the camps and clubs, team members actively engaged in the LPS cycle, undertaking activities such as learning how to teach and interact with children, practicing teaching skills, and serving as tutors for junior participants. Since team members themselves are also juniors, four adult volunteers were requested to pass background checks and youth protection training to oversee the summer camps and assure the smooth operations of each summer camp.

Assessment of the LPS Framework

Assessment of the LPS framework was performed based on four criteria: performance of the team in FTC competition on robot design and community outreaches, achievement of individual team members through the LPS training framework, and evaluation feedback from summer campers.

Artifacts of team achievements were compared with the best performance in the states and world competitions. Individual achievements were documented for state/national/international level recognized awards. Quantified results were analyzed with respect to the averages and standard deviations.

Results

K-12 Students trained with LPS framework.

Implementation of the LPS framework was conducted for the student group from August 2020 to August 2023. Each member participated for over 1,900 hours for learning, practices, and service as described below. In addition, a total of 130 2nd - 8th graders were trained with the LPS framework in a short period of time to validate the transformability and scalability of the LPS model.

Learning and Professional Connections

From 2020 to 2023, the team identified a total of 26 mentors spanning various backgrounds, including schools, universities, research institutes, companies, businesses, and other FTC teams. These mentors generously provided the team with a total of 48 skill development sessions. The distribution of mentors based on their professions and the topics and numbers of learning sessions are shown in Figure 2.

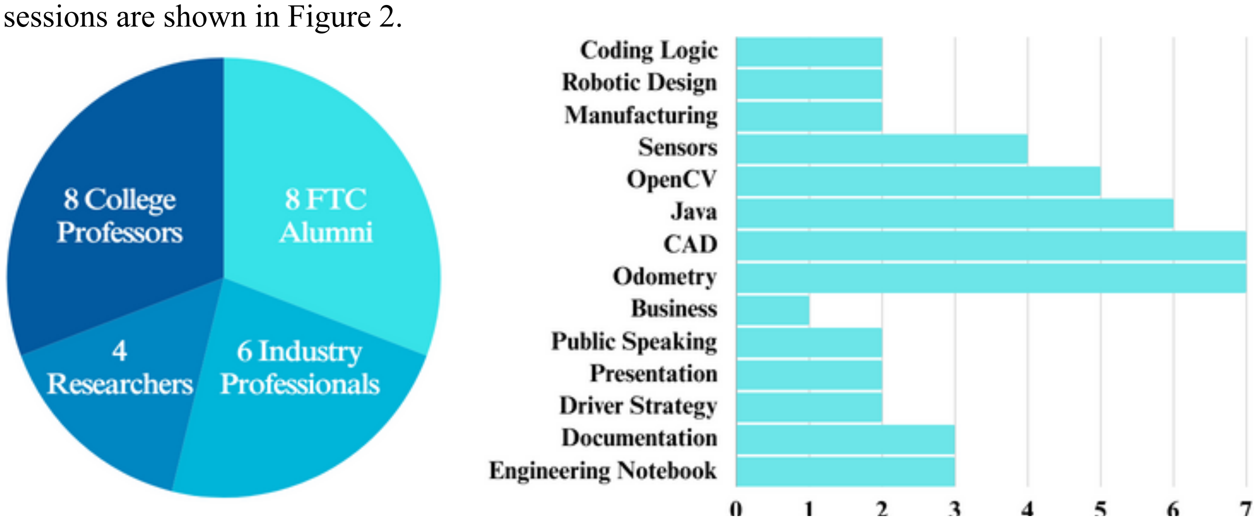

Figure 2: Connection with professionals and learning sessions. Distribution of mentors' professions is shown as a pie chart (Left). Topics and numbers of learning sessions are shown as a bar chart (Right).

Practice Sessions and Outcomes of Robot Design

An average of 515 practice hours per year were recorded for sessions on weekends and school breaks, comparable to the workload of two regular courses per academic year for high schoolers. Themes of practice meetings varied, from brainstorming game strategy to designing the robot, from designing team T-shirts to discussing outreach events, and from writing the engineering book to preparing for judge room presentations. Most of the practice sessions were allocated for the central task: design and building a robot for competition. Whiteboard discussions were adopted for team members to generate, share, and discuss ideas, followed by CAD, CNC, manufacturing, and 3D printers to prototype, and test components to reduce cost. Commonly, each manufactured part was iterated 4-6 times to improve the performance of the robots.

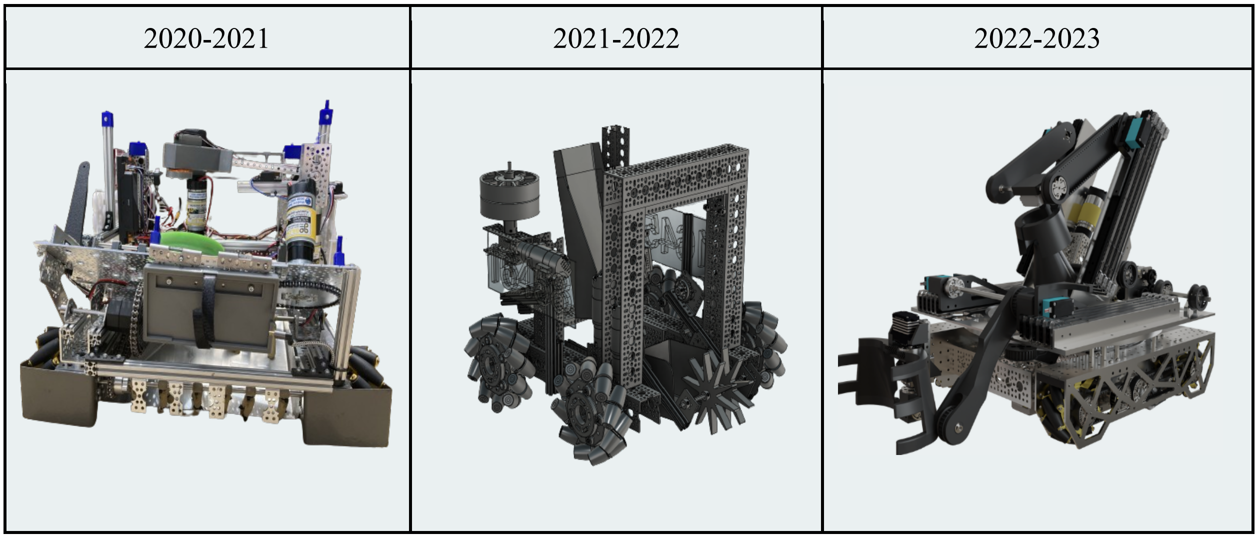

Figure 3: Robots developed for FTC competitions from 2020 to 2023.

Table 1: Details for innovations and components adopted to design and build a robot during 2020-2023

	Innovations	Sensors	Software	% CAD
2020 - 2021	- Active intake allowed for intaking in any orientation	- Camera to detect object location - Touch sensors to detect object positioning	- Encoder drive for autonomous movement	- 5% - Small parts were 3D printed
2021- 2022	- Transfer mechanism used to control objects entered the robot	- Camera detection - 2 color sensors used to detect when objects enter the robot	- Encoder drive for autonomous movement - Machine learning to detect objects	- 20% - Some major components were designed in CAD
2022 - 2023	- Rotational movement on both intake and delivery using lazy Susan bearings for increased flexibility - Entirely modular design	- Camera detection - Distance sensor to auto-close “claw” - Magnet sensors to re-localize extensions - External encoders to track the robot’s position	- Finite State Machine integrated for multitask functionality - External encoders and Roadrunner for accurate autonomous movement -OpenCV to detect object location	- 100% - Entirely designed in Fusion360 before manufacturing

Figure 3 shows three robots designed, built, and used for competition for each year from 2020 to 2023, along with explanations of the technical innovations, sensors, software used on each robot as well as the skills needed for these innovations in Table 1. The authenticness of the robots and continuously enriched skills illustrate the growth of learning and practice outcomes.

Sustainability of the LPS Framework

Sustaining the team's momentum involved a fundamental focus on fundraising, which served as a crucial avenue for honing communication and networking skills. The team fund primarily supported expenses such as parts acquisition, competition registration, team-building activities, service events, material printing, and pit decoration. The financial dynamics for each year, encompassing both incomes and expenses, are detailed in Figure 4. In the year of 2020 (Year 1), the team generated an income of $12,740 with expenses amounting to $9,747.06. Year 2 saw an income of $9,882 and expenses of $5,194.34, partly attributed to reduced parts costs through the reuse of existing components. Year 3 reflected an income of $14,351 with expenses totaling $10,296.

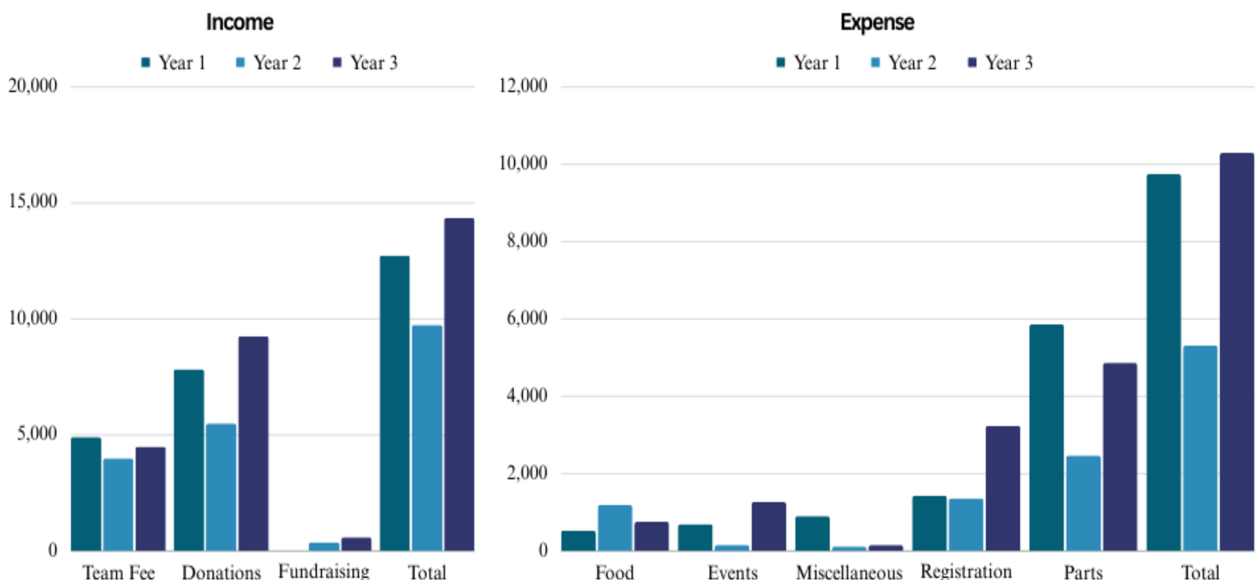

Figure 4: Income and expenses in a three-year-period of implementing the LPS framework to train students participating in FTC competitions.

Service for Community Engagement and Impacts

Service was implemented at a local, national, and global scale, with each team member contributing about 165 hours per year on promoting STEM and robotics education. The team collaborated with 85 partners, which included 10 schools, 9 industries, 6 businesses, 3 non-profits, 2 foundations, 5 government officials, and over FTC 50 teams. The LPS-trained team implemented 54 service-learning projects, which included 45 local activities and 9 national and international activities. These included Zoom presentations and on-site visits for international students in 4 continents, attending national conferences to advocate for STEM funding, creating summer camps for local 2nd - 8th graders, founding junior robotics clubs at schools, creating podcasts and other digital content on STEM professionals, launching regional FTC team conference and publishing conference proceedings, offering clinics for rookie teams, delivering presentations to sponsors, etc. Team members developed 23 different presentations and curriculums for community members with varied levels of needs.

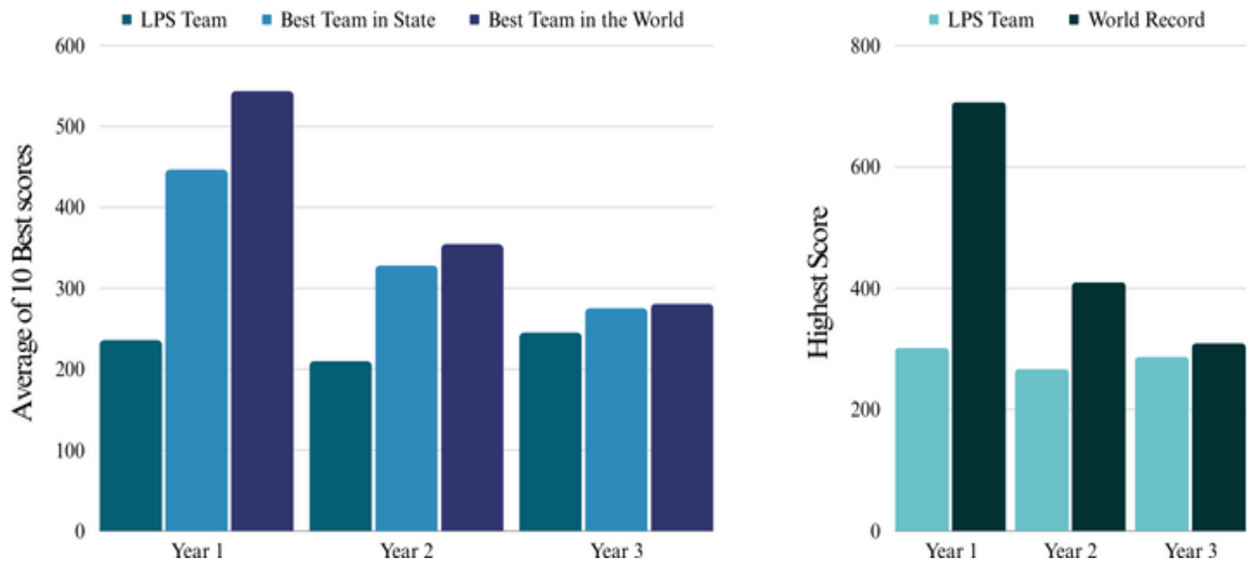

Figure 5: Scores of the LPS-trained team in comparison to the best teams in the State and World Championships with respect to the average the best 10 scores (Left) and the highest score from a robotic competition game (Right).

<u>LPS Outcomes on FTC Competitions from 2020 to 2023</u>

Figure 5 illustrates the average of the 10 best scores of the LPS-trained team in the FTC state and world competitions from 2020 to 2023. As the game changes annually and scores lack standardization, there has been a noticeable decline in the points achieved by the world's top-performing team each year, likely due to the increased difficulty level of the tasks required by the game manual. Nevertheless, the disparity between the LPS team and the world's best team has significantly narrowed over time, evident in both average scores and individual highest scores.

In Year 1 (2020-2021), the average score of the world's best team exceeded that of the LPS team by more than double. By Year 3 (2022-2023), the averages were relatively close, differing by only 40 points. The gap between the highest scores achieved by the LPS team and the world record has also notably diminished over the three-year period. This trend is not limited to robot game awards but is also observed in judge room accolades.

The LPS framework, well-suited to FTC competitions, places significant emphasis on judge room presentations. During these presentations, teams were tasked with showcasing the most innovative aspects of their robot and any community service initiatives they have undertaken. The team's accumulated awards over the years when the framework was implemented are detailed in Table 2.

The LPS trained team's competition performance demonstrated improvement over the three years of training. In Year 1, the team did not progress to the State Tournament and received no awards at the Regional Tournament. By Year 2, the team received an award at the Regional Tournament but failed to advance to the State Tournament. In Year 3, the performance was marked by a significant leap, with the team becoming qualified for the State and World Tournaments and receiving awards in both.

Table 2: Awards received by year at League (local), Region, State, and World Championship during the period of 2020 - 2023

Level	Year 1 (2020 - 2021)	Year 2 (2021 - 2022)	Year 3 (2022 - 2023)
League	Inspire Award (3rd Place) Think Award (1st Place) Finalist Alliance Captain	Inspire Award (2nd Place) Connect Award (1st Place) Control Award (2nd Place) Winning Alliance Captain	Inspire Award (1st Place) Winning Alliance Captain
Region	None	Connect Award (3rd Place)	Inspire Award (1st Place) Winning Alliance 2nd Team Selected
State	Did not advance	Did not advance	Design Award (1st Place) Winning Alliance 2nd Team Selected
World	Did not advance	Did not advance	Think Award (2nd Place in Ochoa Division)

The enhancements in the team's performance at the FTC competitions underscore the efficacy of the LPS framework. Since students build the robot themselves, improvements in robot performance directly reflect advancements in their technical skills. Without enhancements in technical abilities like CAD and Odometry in Year 3, there would be no discernible improvement in the performance of the robots in the games. Moreover, progress in judge room awards is closely linked to overall improvement in non-technical skills. As these awards depend on the team's presentations and actual service activities undertaken, an increase in such awards indicates improvement in both soft skills and impact gained by serving the community.

<u>Individual Achievements from Team Members through Trainings with LPS Framework</u>

As a direct result of the LPS training, the team has had 1 Presidential Volunteer Service Award Gold Winner for 3 consecutive years, 1 Congressional App Challenge Winner, 5 FTC Dean’s List Semifinalist, 2 FTC Dean’s List Finalist, 1 National Junior Honor Society (NJHS) member, 1 Science National Honor Society (SNHS) member, and 4 National Honor Society (NHS) members. 1 member has gained the official Autodesk CAD Certificate. These individual achievements serve to bolster the identity of our students and their engagement in STEM fields. All team members have chosen STEM as their career path.

<u>Results from Summer Camps</u>

Figure 6 illustrates feedback from three summer camps. Each camp adopted the LPS framework and trained 20 students from grades 2-8 for a week. To ensure direct hands-on experiences, four students shared one set of hardware during practice sessions. Across the three camps, there was a noticeable increase in positive feedback regarding returning to the camp, participating in FIRST robotics programs, and recommending the camp to others. This improvement confirms the effectiveness of the LPS framework to prepare the team to make a bigger and more positive impact as the trainers accumulate more experiences through the learning-practice-service cycle. Notably, one child from an economically disadvantaged background was given priority for enrollment.

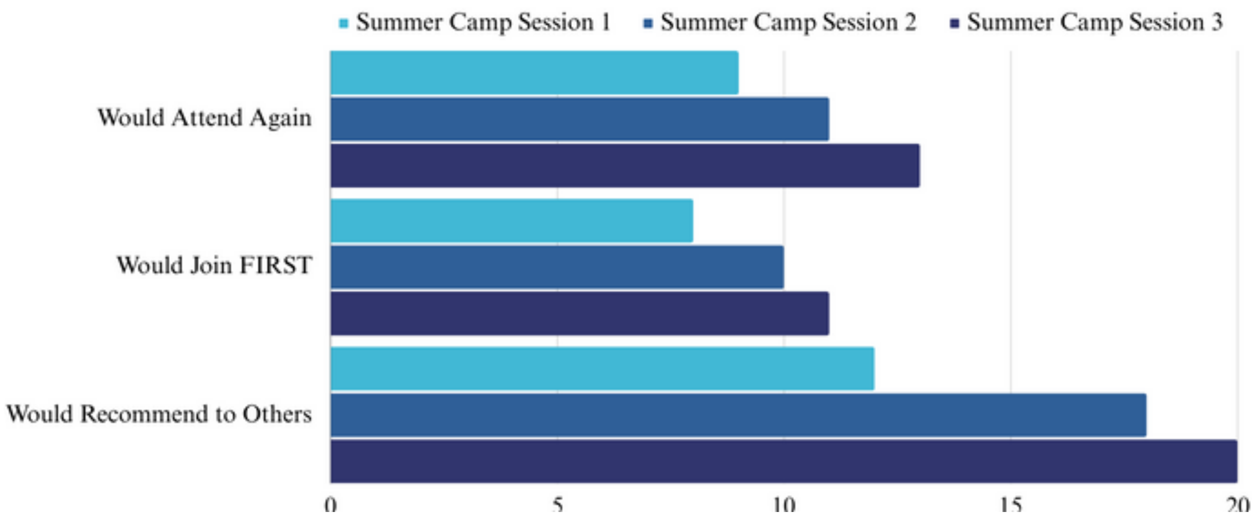

Figure 6: Feedback from 60 campers of three summer camps.

Conclusion And Discussion

This study proposes an innovative learning-practice-service framework on robotic education, spanning three years of implementation with 7th-12th graders during a pivotal phase of their academic journey. Central to this framework is its integration within internationally recognized FTC Competitions, distinguished by its robust emphasis on real-world applications, fusion of technical and non-technical skills in learning and practice, and cultivation of leadership and community engagement.

Under this framework, students undergo comprehensive training encompassing mechanical design, machining, programming, sensor integration, as well as non-technical proficiencies such as presentation skills, communication, networking, and fundraising. This holistic approach equips teams not only for success in FTC World Tournaments but also lays a solid foundation for their future career development.

Remarkably, students exhibit a resolute commitment to STEM disciplines and advocate for STEM education within local, national, and international spheres. Their engagement in learning, practice, and service not only elevates their academic performance, evidenced by prestigious awards and memberships in honor societies, but also extends into impactful outreach initiatives.

These projects, designed with creativity and purpose, have reached children across the K-12 spectrum on four continents, yielding tangible and positive outcomes.

The positive outcomes of the LPS framework on robotic education are largely a result of the collective efforts of not only the students but also dedicated coaches, mentors, sponsors, who have generously applied their expertise and resources to guiding and strengthening the students' endeavors.

Each student has invested a significant amount of time and effort, devoting over 1,900 hours to organizing and executing numerous learning-practice-service sessions and projects throughout their demanding 7th-12th academic years. Their ability to manage these commitments alongside their regular schoolwork underscores their self-motivation and dedication. This illustrates how motivated and dedicated students, when appropriately challenged and empowered by an effective educational framework, can achieve remarkable results.

Crucially, the unwavering support of families and professional communities has been instrumental throughout the implementation of the LPS educational framework. Their involvement in state and world tournaments, as well as conferences, highlights the collective effort required to foster student success not only from traditional education effort at schools. While traditional in-class education provides a foundational understanding of science and engineering, there is a clear need for our educational systems to allocate systematic and specific resources to enrich educational methodologies and media.

Moreover, the extensive and sustained dedication from these students, along with their rigorous research endeavors, equates to the workload typically associated with two high school courses per year. This level of commitment could readily qualify as capstone projects or independent study credits. Regrettably, very few school districts presently accommodate such research credits within their established curricula. Addressing this issue presents an emerging challenge for educators and administrators: how to design supportive and flexible school curricula that seamlessly integrate project-based and service-based learning initiatives into students' academic education. By developing an advanced school curriculum that incorporates these learning methodologies, a ripple effect can occur, benefiting a broader spectrum of students across various school districts.

The LPS framework has only been designed and implemented for three years and needs to be further improved. Potential directions are listed as follows. 1) Develop age-specific curricular modules by integrating the outcomes of summer camps and school clubs. This approach will enhance the transformability and scalability of the framework. The resulting curricular modules will be made available online through our YouTube channels, thus enriching community resources. This initiative holds particular significance for students with limited resources for robotics education and those participating in other robot competition programs. 2) Expand the inclusion of larger cohorts within the LPS framework. This expansion will enable us to gather more comprehensive data and insights, thereby facilitating further improvements to the framework. 3) Explore the feasibility of collecting data on the long-term impact of the LPS framework on the academic and professional trajectories of specific cohorts of students post-high school education. This longitudinal analysis will provide valuable insights into the effects of the

LPS framework on students' lives beyond their secondary education. By pursuing these avenues, we aim to enhance the effectiveness and reach of the LPS framework, thereby maximizing its benefits for students and communities alike.

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References

[1] M. Grubbs, "Robotics intrigue middle school students and build STEM skills," *Technology and engineering Teacher,* vol. 72, no. 6, p. 12, 2013.

[2] A. Khanlari and F. Mansourkiaie, "Using robotics for STEM education in primary/elementary schools: Teachers' perceptions," in *2015 10th International Conference on Computer Science & Education (ICCSE)*, 2015: IEEE, pp. 3-7.

[3] J. Clemmons and Y. F. Jin, "Reinforcement Learning-Based Guidance of Autonomous Vehicles," in *2023 24th International Symposium on Quality Electronic Design (ISQED)*, 5-7 April 2023 2023, pp. 1-6, doi: 10.1109/ISQED57927.2023.10129362.

[4] Z. Wang *et al.*, "A Vision-Based Low-Cost Power Wheelchair Assistive Driving System for Smartphones," in *2022 IEEE 24th Int Conf on High Performance Computing & Communications; 8th Int Conf on Data Science & Systems; 20th Int Conf on Smart City; 8th Int Conf on Dependability in Sensor, Cloud & Big Data Systems & Application (HPCC/DSS/SmartCity/DependSys)*, 18-20 Dec. 2022 2022, pp. 1979-1986, doi: 10.1109/HPCC-DSS-SmartCity-DependSys57074.2022.00295.

[5] S. Zhou, M. Xie, Y. Jin, F. Miao, and C. Ding, "An End-to-end Multi-task Object Detection using Embedded GPU in Autonomous Driving," in *2021 22nd International Symposium on Quality Electronic Design (ISQED)*, 7-9 April 2021 2021, pp. 122-128, doi: 10.1109/ISQED51717.2021.9424308.

[6] D. C. Williams, Y. Ma, L. Prejean, M. J. Ford, and G. Lai, "Acquisition of physics content knowledge and scientific inquiry skills in a robotics summer camp," *Journal of research on Technology in Education,* vol. 40, no. 2, pp. 201-216, 2007.

[7] F. R. Sullivan, "Robotics and science literacy: Thinking skills, science process skills and systems understanding," *Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching,* vol. 45, no. 3, pp. 373-394, 2008.

[8] A. M. Ortiz, *Fifth grade students' understanding of ratio and proportion in an engineering robotics program*. Tufts University, 2010.

[9] M. U. Bers, L. Flannery, E. R. Kazakoff, and A. Sullivan, "Computational thinking and tinkering: Exploration of an early childhood robotics curriculum," *Computers & Education,* vol. 72, pp. 145-157, 2014.

[10] C. Kim, D. Kim, J. Yuan, R. B. Hill, P. Doshi, and C. N. Thai, "Robotics to promote elementary education pre-service teachers' STEM engagement, learning, and teaching," *Computers & Education,* vol. 91, pp. 14-31, 2015.

[11] Y. Jin, C. Qian, and S. Ahmed, "Closing the Loop: A 10-year Follow-up Survey for Evaluation of an NSF REU Site," in *ASEE Annual Conference and Exposition, Aug 23 2022* Minneapolis, MN. [Online]. Available: https://peer.asee.org/41048. [Online]. Available: https://peer.asee.org/41048

[12] S. Anwar, N. A. Bascou, M. Menekse, and A. Kardgar, "A systematic review of studies on educational robotics," *Journal of Pre-College Engineering Education Research (J-PEER),* vol. 9, no. 2, p. 2, 2019.

[13] M. E. Karim, S. Lemaignan, and F. Mondada, "A review: Can robots reshape K-12 STEM education?," in *2015 IEEE international workshop on Advanced robotics and its social impacts (ARSO)*, 2015: IEEE, pp. 1-8.

[14] B. S. Barker and J. Ansorge, "Robotics as means to increase achievement scores in an informal learning environment," *Journal of research on technology in education,* vol. 39, no. 3, pp. 229-243, 2007.
[15] N. Rusk, M. Resnick, R. Berg, and M. Pezalla-Granlund, "New pathways into robotics: Strategies for broadening participation," *Journal of Science Education and Technology,* vol. 17, pp. 59-69, 2008.
[16] B. Ericson and T. McKlin, "Effective and sustainable computing summer camps," in *Proceedings of the 43rd ACM technical symposium on Computer Science Education*, 2012, pp. 289-294.
[17] S. Van Delden and K.-P. Yang, "Robotics summer camps as a recruiting tool: A case study," *Journal of Computing Sciences in Colleges,* vol. 29, no. 5, pp. 14-22, 2014.
[18] I. J. B. Alvarez, "Introduction to robotics: Importance of a summer camp as a recruiting tool for future university students," *IEEE Revista Iberoamericana de Tecnologias del Aprendizaje,* vol. 12, no. 2, pp. 71-75, 2017.
[19] S. Papert, "The children's machine: Rethinking school in the age of the computer," *New York,* 1993.
[20] VEX Robot Event. "Robotics education & competition foundation - Inspiring students, one robot at a time." https://www.robotevents.com/ (accessed 01/01, 2024).
[21] Best Robotics. "Boosting Egnineering Science & Technology." https://www.bestrobotics.org/site/ (accessed 04/02, 2024).
[22] World Robot Olympiad. https://wro-association.org/ (accessed 04/02, 2024).