International Collaboration to Increase Access to Educational Robotics for Students

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***Abstract*—SmartMotors are low-cost, trainable robotic systems that aim to lower the barriers to entry into robotics. Many kits and online tools have been developed for teaching children about robotics, enabling an increasingly widespread integration of engineering and robotics into classrooms. However, despite their many positive features, issues of equitable access for students in under-resourced classrooms have emerged: high costs, the need for internet connection and computers, and technical expertise on the part of teachers all limit their adoption. We propose to develop an affordable robotic technology geared specifically towards diverse educational contexts that enables students of all ages and backgrounds to gain exposure to the field. This paper describes the international collaboration in developing SmartMotors, details various prototypes built with locally available materials, and describes how teachers can implement SmartMotors in workshops and classrooms. SmartMotors are a low-cost solution to teaching elementary and middle school students about robotics and Artificial Intelligence using readily available materials. Users can train a motor to run to various positions corresponding to different sensor inputs, enabling students to bring their engineering projects to life. Shifting the focus from coding to training robots eliminates the need for students to have access to computers and the internet to engage in hands-on robotic activities. Furthermore, the system can be developed with materials already on-hand in different countries. The development of SmartMotors is creating an international community of engineers and educators contributing to coming up with designs and testing different materials available in their settings. This global network enables a wide range of educational contexts to be core to the development of the system. Studying students' engagement with the system during workshops further ensures the product is accessible and valuable to students' and teachers' learning in various settings.**

***Index Terms*—education robotics, international collaboration, SmartMotors**

I. Introduction

In recent years, robotics education has become increasingly integrated into classrooms of all ages [1]. Educational robotics facilitate hands-on exploration, a core part of learning for children [2] to build an understanding of the world through experience and discovery. Learning with robots can create a fun and engaging environment through which students learn essential and transferable skills like collaboration, interpersonal communication, creativity [3] [4], critical thinking, problem-solving [4], and inquiry [2]. In addition, robotics activities can incorporate different subjects, such as science, art, and literacy [5] [6] [7], enabling students to personally engage with real-world applications of the material they are learning in the classroom.

However, the availability and the high cost of the existing systems like LEGO robotics kits, Makeblocks, and tools like Scratch, Cognimates, or Teachable Machines present issues of equitable access for students worldwide [8] [9] [10]. Many of these technologies require access to the internet and computers and technical expertise from instructors to effectively use them. Therefore, we believe affordable robotic technologies geared towards diverse educational contexts must be developed for a wide range of students from diverse socioeconomic backgrounds and worldwide to gain exposure to robotics [11].

At the Center for Engineering Education and Outreach at Tufts University (CEEO), US, researchers have created a robotics system called SmartMotors to address this issue. A SmartMotor is a hobby servo motor connected to a sensor, such as a light sensor. This motor can be trained to move to different positions with the sensor readings. They are collaborating with the researchers in Brazil to build and implement this technology in a Brazilian context. SmartMotors aim to lower the barrier to entry to robotics by shifting the focus from coding to training robots, thereby eliminating the need for computers or access to the internet for students to engage in robotics. Through this partnership, we intend to develop an accessible robotics system using locally available resources and expertise to implement robotics education in Brazil. The goal of this partnership is to create a model for implementing SmartMotors in classrooms around the world.

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II. Background

SmartMotors are pre-programmed motors that can be trained to respond to different sensor inputs. The central idea behind the system is that shifting the focus from coding to training robots increases accessibility to robotics for students in several key ways. First, as they do not require computers or access to the internet, SmartMotors are accessible to students in low-resourced schools, which may already lack sufficient funding to implement hands-on STEM activities. In addition, SmartMotors are built using locally accessible, low-cost materials and can be adapted to fit the resources already available in a classroom.

SmartMotors are intended to be a tool that can be implemented in various projects and classroom settings. The shift to training also makes SmartMotors create a layered complexity to the system, making it approachable to both STEM and non-STEM instructors and students with limited experience with robotics. SmartMotors can be used in projects in all subjects, integrating STEM with art, storytelling, and other relevant topics to students. As students and instructors become more comfortable with the system, they can retrain and implement it into their projects more complexly. In more advanced classrooms, the system's use of artificial intelligence can be used as an opening point for a discussion on AI, a subject critical to understand for digital literacy [12].

In the following sections, we will describe in detail the international collaboration and the work that has been done on SmartMotors in the United States and Brazil.

III. Details of Collaboration

The collaboration between the Tufts University Center for Engineering Education and Outreach (Tufts CEEO) in the US and the Brazilian Creative Learning Network (BCLN) in Brazil is part of the LEGO Foundation Tech and Play initiative that connects global organizations to make classroom technology more playful. The Federal University of São João del-Rei (UFSJ) and the Federal Institute of Education, Science, and Technology of Rio Grande do Sul (IFRS) represent BCLN in this collaboration. The initiative aims to equip children with skills to thrive in a technology-driven world by allowing them to express themselves creatively through coding, tinkering, and robotics.

A. Tufts CEEO

The Tufts CEEO is an interdisciplinary center at the Tufts School of Engineering that aims to create the next generation of problem solvers through engineering education. In May 2021, the CEEO hosted an online hackathon with educators in Brazil and the USA, in which they introduced the idea of SmartMotors in robotics education. Participants used a pre-programmed Grove Beginner Kit For Arduino and a servo motor for the hackathon to tell a story using the SmartMotors. The participants created unique and creative projects and reflected that this technology could also bring out the creativity in students.

Fig. 1. Prototype of SmartMotors developed at Tufts CEEO.

Based on the feedback from the hackathon participants, researchers at the Tufts CEEO began developing SmartMotors prototypes[1]. Fig. 1 is an example of a SmartMotors prototype created at CEEO. We received regular feedback from the Brazilian counterparts on the prototypes. Realizing that replicating this system in Brazil would be difficult, we began efforts to redesign it with locally available resources to make this technology viable for schools in Brazil.

After communicating online for over a year, the Tufts CEEO hosted Brazilian collaborators to work in person for three weeks in the summer of 2022. Along with summer interns at the CEEO, they explored different materials and techniques for prototyping SmartMotors. In November 2022, researchers at the Tufts CEEO visited the two universities in Brazil exploring SmartMotors and discussed the implementation of SmartMotors in classrooms with their students and partner teachers. They helped run the SmartMotors activities with the students at the festivals and made plans to work with local school teachers in designing robotics activities using SmartMotors.

B. UFSJ/CyRoS

The Federal University of São João del-Rei (UFSJ) hosts the Center for Innovation, Creativity, and Technologies for Human Development (C-ProH). The space is managed by the Center for Robotics and Assistive Technologies (CyRoS) at UFSJ and integrates several research, educational, innovation, and extension projects. CyRoS studies project-based and play-based learning approaches, with a particular focus on creative learning [13], tinkering [14], and STEAM education [15]. Since 2011, the group has explored low-cost technologies like Arduino boards to develop educational robotics technologies accessible to Brazilian public schools and non-traditional learning environments. Collaborating to create a Brazilian version of SmartMotors using easily accessible materials is a new step in advancing this goal.

The collaboration began with developing a SmartMotors extension in DuinoMaker that can convert any Arduino-based educational kit into a SmartMotor. DuinoMaker [16] is a platform adapted at UFSJ from ArduBlokly that enables

[1]SmartMotors page: https://www.ceeoinnovations.org/fetlab

technologies based on Arduino boards to be programmed using blocks. The extension allows educators to select the physical connections between sensor and actuator components and needs a computer to send the SmartMotor programming to the box only once. After this, students can directly program the system to create their projects without a computer. Fig. 2 shows the DuinoMaker Interface and an example of an Arduino kit used as a Brazilian SmartMotor system. DuinoMaker is available on http://duinomaker.org[2]

Fig. 2. DuinoMaker visual programming interface and example of an Arduino board-based kit being assembled as a SmartMotor.

DuinoMaker blocks are an essential step in making SmartMotors available to students. However, teachers must make the electronic connections in the kit available beforehand, which may be challenging for some. As such, the next step was to create a SmartBox at UFSJ similar to the one developed at Tufts using locally available materials like Arduino-based boards (Fig. 3 a).

The first SmartBox maps two different sensor values onto two different actuator positions. The possibility of creating projects using a combination of two different sensor measurements and relating them to two actuator positions is sufficient for beginner students and functions as the low floor stipulated by creative learning (CL) educational approach. However, CL also advocates that students should be free to explore more complex projects, the so-called high ceiling. Therefore, the next step was to expand the system's functions by developing a SmartMotor system programmable with a display interface (Fig. 3 b). Vector blocks were also included on DuinoMaker to allow the SmartMotor to be programmed with more than two sensor-actuator value combinations. The codes and CAD files are available on a publicly shared Google Drive[3].

Fig. 3. SmartBoxes Arduino Uno-based with and without Display.

During the Tech and Play Hackathon held at Tufts in June 2022, the team collaborated to improve the fabrication of the PCBs. As a result, ten SmartMotor Arduino Uno systems were made and were used by the public that visited the Festival of Invention and Creativity held in November 2022 at UFSJ. The Tufts team and the Brazilian Creative Learning Network attended this event. Fig. 4 shows the space for experimentation with the SmartMotor system during the festival.

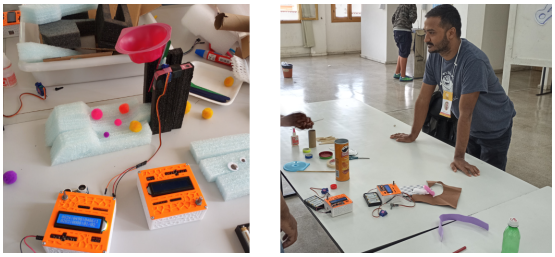

Fig. 4. Smartbox presentation at Festival of Invention and Creativity in São João del-Rei, Brazil.

C. IFRS/Poalab

The Federal Institute of Education, Science, and Technology of Rio Grande do Sul (IFRS) at the Porto Alegre campus is home to the Fab Lab POALAB, which is also one of the BCLN hubs. The lab is centered around the digital fabrication and creative learning approach, enabling the community to develop solutions using technology while learning.

To achieve this goal, we began exploring local materials in the lab that could be utilized in the fabrication of SmartMotor PCBs. Additionally, we contacted teachers to identify the robotics kits available at schools. We discovered that most public schools in the Rio Grande do Sul state possess robotics kits equipped with Arduino Uno boards, motors, wheels, and other electronic components ideal for building our project.

The process of teachers and students designing and building their PCBs for the SmartMotor project could serve as an exceptional learning opportunity about electronics and coding while incorporating SmartMotors into classrooms. To test the feasibility of the project, we designed two PCBs: one using acrylic and copper adhesive as an Arduino Uno shield and the other with a phenolic board that could be used with an ESP8266-nodeMCU board, which is readily accessible to most schools at a low cost.

For the first PCB, we used the laser cutter to mark tracks and create holes in a 3mm acrylic sheet[4]. Subsequently, we employed the vinyl cutter to cut the copper adhesive and construct the PCB tracks, which we then applied to the acrylic. Finally, we soldered the shield components and connected them to the Arduino board. Fig. 5 shows the development of this first iteration with the different materials and techniques, and Fig. 6 presents the final prototype with acrylic and copper adhesive during the festival.

For the second PCB, we utilized a phenolic board and a milling machine. This model featured an 8x8 LED matrix and an ESP-8266-nodeMCU board (Fig. 7).

[2]DuinoMaker can be accessed at http://duinomaker.org

[3]Shared Google Drive can be accessed at bit.ly/3oqk3gk

[4]All files can be accessed at https://github.com/poalab/smart_motors/

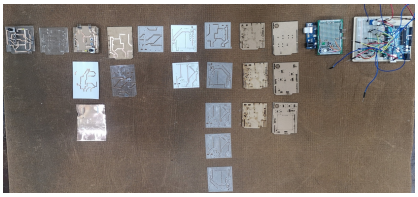

Fig. 5. First PCB design Process.

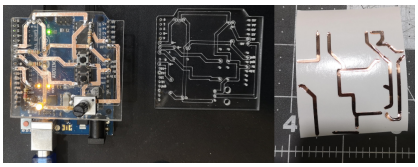

Fig. 6. First PCB.

During our visit to the Tufts CEEO, we had the opportunity to explore various fabrication techniques and prototypes. In addition, we collaborated on refining the code for SmartMotors in both C and MicroPython and discussed circuit design strategies. Following our meeting at Tufts, we reconvened in Porto Alegre, where researchers from Tufts and IFRS discussed the project with Brazilian teachers. We also established plans for an extension course scheduled to take place in the first semester of 2023 (Fig. 8). This collaborative course will be jointly led by the Tufts CEEO and IFRS, specifically targeting teachers from robotics classes in public schools in Rio Grande do Sul, Brazil.

IV. Discussion

Through the Tufts CEEO, UFSJ/CyRoS, and IFRS/Poalab efforts, we aim to create an educational robotics technology that can be adapted for use in diverse classrooms. Several versions of SmartMotors have been created, including ones built on Arduino-based boards that are affordable and widely available in Brazil. The collaboration is taking place through Zoom conversations, in-person visits, and hackathons and with the input of teachers in each place. The Tufts CEEO has been running SmartMotors tests in workshops and classrooms with students from second grade to high school. The results have shown that students, including those without prior experience with robotics, can understand the idea of training a robot and use it in projects to bring their ideas to life. For example, students have created projects to tell stories, made drawing machines, and built games and ”smart house” projects using SmartMotors. In a second and third-grade classroom, the students used them to build an analog dashboard to differentiate between conductors and insulators. Through each iteration and test, we discover the positive aspects and limitations of the SmartMotor system. In addition, the lessons learned from each group of researchers' explorations enable us to come together and better localize and contextualize the technology, making it accessible to a broader range of classrooms.

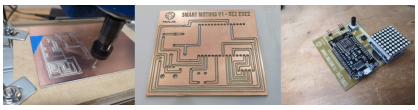

Fig. 7. Second PCB.

Fig. 8. Meeting with teachers at POALAB.

A benefit of an internationally-developed technology is that it is designed to be adaptable for use in a diverse range of classrooms and educational contexts and applicable in a wide range of projects that are contextualized to each place. Teachers can adapt the system to fit in with their curriculum, and building the system itself can be a valuable learning experience for students. Furthermore, the international community of engineers and educators contributing to designing and testing SmartMotors creates a link for students across cultures; in future implementations of the system in classrooms, students can draw from and share their ideas with others from across the world, fostering cross-cultural connection and gaining exposure to ideas sparked from a very different way of life than their own.

V. Future work

At IFRS, we aim to determine the available robotic kits and materials in schools and collaborate with teachers to develop new SmartMotor systems using these supplies. In addition, the goal is to train teachers in the design of SmartMotor PCBs. At some schools, older students can participate in this process and learn about fabrication, PCB design, electronics, and coding, and younger students learn about robotics and AI using the created SmartMotors.

The following steps at UFSJ are to develop new SmartMotor models based on Arduino WiFi and to use an LED matrix as an interface. In addition, we are remixing workshops based on creative learning to use SmartMotors instead of technologies that require computers. We are also working to develop pedagogical support materials for teachers to use SmartMotors. Teachers from partner schools will be invited to test and evaluate these materials and workshops and then implement them with their students.

We intend to start a Community of Practice covering Latin American partners in the Spanish LCL (Learning Creative Learning) group. This community also uses Arduino as the basis for several robotics projects. In addition, the SmartMotors versions developed at UFSJ and IFRS can serve as inspiration or be replicated in other countries in Latin America, Africa, and Asia, where Arduino-based boards are more affordable and easily accessible.

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