Introductory Activities for Teaching Robotics with SmartMotors

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Abstract. In this research paper we describe the activities designed for a 5 day engineering design workshop using an educational robotics tool called SmartMotors. SmartMotors are low cost solutions to teach elementary and middle school students about robotics and Artificial Intelligence in under-resourced classrooms. In a few simple steps these motors can be trained by the users to run to various states corresponding to different sensor inputs. We believe that the low cost and trainable aspects of SmartMotors will reduce barriers of entry for both teachers and students in introducing robotics in classrooms and increase student access to robotics and engineering. In the summer of 2022, we used one of our prototypes to run a usability study in a workshop with ten middle school students aged 12-15. The students participated in an hour-long engineering design workshop for five days, and each day they received different prompts along with necessary scaffolding. The participating students had limited prior exposure to robotics and AI. By the end of the workshop, the students were able to train robots in group projects that reflected their individual interests. In this paper, we talk about the students' journey, starting with building simple projects and subsequently gaining the skills and confidence to showcase diverse and complex designs. We will then discuss the affordances of the tool and explore the opportunities and limitations of SmartMotors in an engineering design workshop.

Keywords: Educational Robotics · Workshops · SmartMotors.

1 Introduction

Integrating robotics in the classroom can be an effective way to teach STEM concepts to students [1][2][3]. It can also enhance the development of skills like collaboration, interpersonal communication, creativity [4][5], critical thinking, and problem solving [5] and inquiry [6]. Properly designed robots can actively engage even younger children in programming and engineering [7]. The idea of using robots in education is not recent. It is rooted in the concepts of constructivism [8][9] and constructionism [10]. With the advancement of technology in recent years educational robotics has found its way into many classrooms. However, many of these technologies require technological expertise and access to computers, which presents issues of equitable access for students whose schools may already lack sufficient facilities and funding to incorporate hands-on STEM activities into their curricula.

LEGO robotic kits have been used all around the world to teach robotics [11]. However, their high cost prevents many schools from incorporating them into their classrooms. Online tools like Teachable Machine [12] and Cognimates [13] require internet connection and computers, and technical expertise on the part of teachers may be necessary for them to be used effectively. Tools like Paperbots [14] are low cost solution to teaching robotics using papers but you still need a computer to code the bots. In order to lower these barriers to entry to robotics, we have devised an idea for an educational robotics toolkit called SmartMotors. SmartMotors are built using easily accessible low-cost materials and do not require computers or access to the internet to program. In a few steps these contraptions can be trained by the users, including students, to build responsive robots. SmartMotors are a low-cost way to bring engineering and robotics into classrooms, making them more accessible to students from a diverse range of backgrounds and from around the world.

2 Background

The central concept of SmartMotors is to train robots instead of coding them. We hypothesize that this shift from programming to training makes SmartMotors approachable and accessible for both STEM and non STEM educators, as well as beginner students. Additionally, the elimination of the need for computers to engage in robotics activities makes this system accessible to users in low-resourced environments. The use of locally available tools and open source instructions to build SmartMotors makes it accessible for educators working with a wide range of materials. Through carefully designed instructions and activities, we can ensure that students have rich meaningful learning experiences using SmartMotors.

As alluded in the previous paragraph, the concept of SmartMotors can be implemented on different existing robotics platforms, as well as microcontrollers. Prior research has shown that many teachers have found ways to build their own robotics kits [15]. To offer these innovative instructors more flexibility, we have documented and made available the instructions for building SmartMotors using different microcontroller boards on a variety of platforms, including Arduino Uno, ESP8266, Seeeduino Xiao, and LEGO SPIKE Prime [16]. We are also developing low cost kits under $20 for teachers who prefer off-the-shelf kits. For the study described in this paper, we used a prototype built using Wio Terminal, a microcontroller from Seeed Studio and a hobby micro servo motor. The Wio Terminal was coded with the SmartMotors algorithm with a friendly user interface.

We envision the use of SmartMotors in an engineering design activity as a tool that enables students to engage in quick builds that showcase complex ideas. SmartMotors allows users to think creatively about the issue at hand without worrying about the technical details. This allows the students to invest more time on the brainstorming, building, and sharing aspects of the engineering design process. The system also provides layered complexity to support learners at different stages. As teachers and students become comfortable with SmartMotors and want to add more complex behaviors to the motors, they can reprogram and modify the behavior of the system. In other contexts, when the focus is on generating ideas for discussions and creating innovative solutions, the system provides plenty of opportunities to foster creativity.

3 Description of the System

Wio Terminal SmartMotors is built using Wio Terminal microcontroller, a hobby servo motor and a Grove rotary encoder. Wio Terminal is an ATSAMD51-based microcontroller developed by Seeed Studio [17]. The Terminal has a wide array of sensors and features like light sensor, microphone, Inertial Measurement Unit (IMU), as well as 40-pin GPIO for expansion. From a pilot study performed with teachers, we learned that the users wanted the system to inform them of its various states. They described that it would be helpful for the system to communicate different sensor and motor values through a graphical representation. The Wio Terminal has a 2.4" LCD color screen on which we designed the user interface. As it is not a touch screen, the buttons were used for user input. The total cost of this robotics kit is under $50.

Fig. 1: The six steps to build Wio Terminal SmartMotors.

3.1 Building Instructions

A computer is needed only once to upload the SmartMotors code to the Wio Terminal. The SmartMotors code is publicly accessible through the QR code on Figure 1 or from the website [16]. Once the Wio Terminal is put into bootloader mode the firmware.uf2 file can be loaded on the Wio Terminal. The steps are outlined in the graphics in detail (Fig. 1).

3.2 Features

The tilt sensor is pre-selected as the default sensor in Wio Terminal SmartMotors. From the Home page (Fig. 2), the users can navigate to the Sensor Select page to choose a different sensor, if needed. On the Sensor Select page (Fig. 3a), the users have three different sensors to choose from - namely, light sensor, tilt sensor, and rotary encoder. The Home page screen shows the icon of the selected sensor as well as its reading with an interactive bar. The motor can be turned in either clockwise or anti-clockwise direction by pressing the 5-way switch left or right, respectively. From the Home page the users can move on to the Train page by clicking the Train icon. In the Train page (Fig. 3b), they can begin pairing sensor values and motor positions by moving the motor to the desired position and pressing the 5-way switch while setting the sensor at a desired reading. Once the user inputs all the desired sensor reading and motor position pairs to the system, they can enter Run mode by clicking the Run icon. In this mode, the motor responds according to the sensor values inputted in the Train mode. The Run page screen (Fig. 3c) shows the current sensor reading and motor position overlaid on a graph of inputted data points. On the Train Model page (Fig. 3d), users can choose to use a categorization model using k-nearest neighbor algorithm or a linear regression algorithm on the training data. The data is not saved on the system, so upon exiting the Run mode page, users must retrain the system with new data.

4 Method

4.1 Activity Prompt Design

SmartMotors are designed to support both teachers and students with little to no experience with robotics. We considered several criteria to build complexity one step at a time while designing the activities. Some of the criteria are listed below:

1. The activities should be designed to support self exploration. The activities should lead to the discovery of the features of the tools.
2. The activities should encourage group work and collaboration between team members.
3. The activities should inspire the students to think critically.

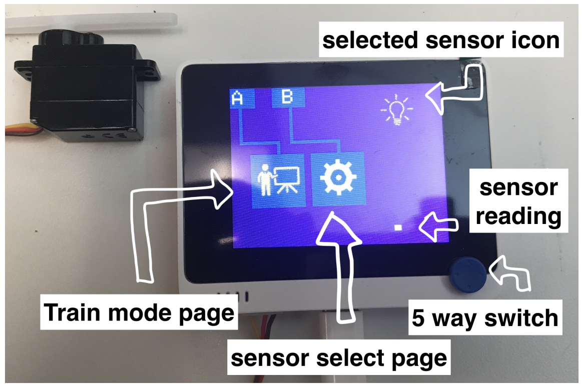
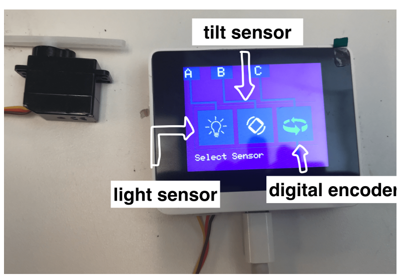
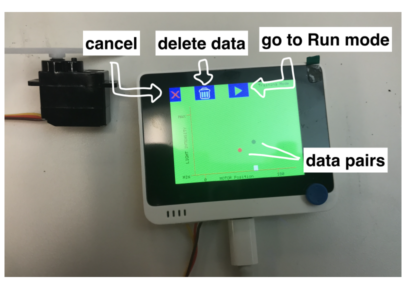


Fig. 2: Homepage of the Wio Terminal SmartMotors user interface.

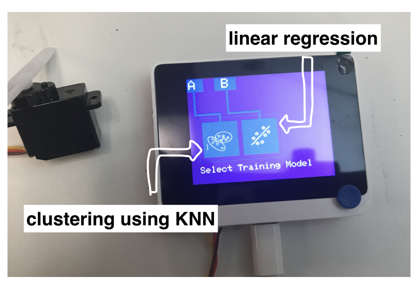


(a) Select sensor page.



(b) Train page.

(c) Run page.



(d) Train Model page.

Fig. 3: Other screens on Wio Terminal SmartMotors User Interface.

4. The activities should support students with different comfort and skill levels. They should lower the barriers to engagement, as well as raise the ceiling of their potential accomplishment.
5. The materials used in the activities should be low cost or easily found around the household.
6. The items that are used in the workshop should be sustainable. Use of recyclable materials like paper and cardboard is encouraged.
7. The activities should be completed within an hour including sharing and feedback sessions.

4.2 Workshop Design

Ten students from grades six to nine participated in the five day workshop. For one hour each day, they worked in small groups, in which they followed the engineering design principle - planning, designing, creating, testing and repeating. Activities were directed using instruction placemats [18]. Placemats are two-sided instructional sheets used in robotics activities. The prompts, challenge questions, examples, and instructions are put in specific order to elicit solution diversity and support self exploration [19]. The activities listed on Table 1 were adapted to the placemat design [16]. Each session began with an introduction to the prompt, planning in small groups, followed by 30-40 minutes of building time. The students were given cardboard, scissors, paper, tape, colored pencils, and hot glue guns to build their projects. At the end of each session, the students shared their project with the larger group. The other student groups gave feedback on the design and contents of the project. The activity was videotaped and the artifacts were photographed for documentation and analysis.

5 Observation and Discussion

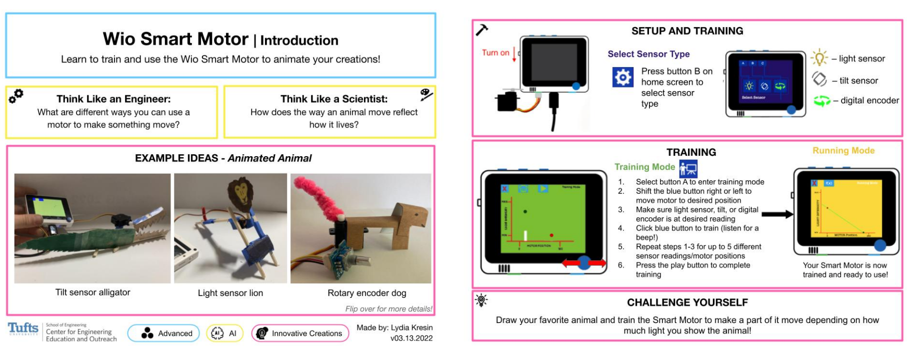
5.1 Day 1: Learn to train and use the Wio SmartMotor to animate your creations!

The first activity was designed for students to learn how to use Wio Terminal SmartMotors. Most of the students were doing robotics activities for the first time, and only one student said they had prior programming experience. The example projects on the placemat (Fig. 4) were simple and easy to build. The second page of the placemat was dedicated to instructing how to train the SmartMotors.

The students worked in groups of two and three. All the groups built simple arm-like attachments to the motors that moved from side to side when the sensor was triggered. In this activity, there was limited solution diversity. The older students seemed to have easier time building with the materials and working in groups. Every group was able to train their SmartMotor by the end of the first day.

Table 1: Wio Terminal SmartMotors activities for robotics.

Day	Activity Title	Learning Goals (Students will be able to...)
1	Learn to train and use the Wio SmartMotor to animate your creations.	train their SmartMotors
2	Use the Wio SmartMotor to tell a story of what you did yesterday using the light sensor.	use the light sensor to train the SmartMotor and use it in their project
3	Use the Wio SmartMotor and tilt sensor to make something relating to the environment.	use the tilt sensor to train the SmartMotor and use it in their project
4	Use the Wio SmartMotor and digital encoder to make a game.	use the digital encoder to train the SmartMotor and use it in their project
5	Choose a sensor and use what you have learned about Wio SmartMotors to tell a story	use SmartMotors to build a project that tells a story that they have read or composed



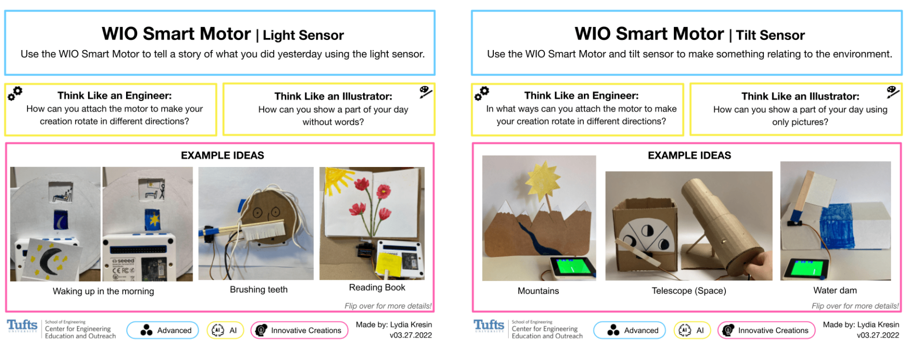
(a) Front page (b) Back Page

Fig. 4: Placemat for Day 1

5.2 Day 2: Use the Wio SmartMotor to tell a story of what you did yesterday using the light sensor!

The prompt for the second day was to use the light sensor to train the SmartMotor and build an artifact to share an event from their personal life. The examples on the placemat (Fig. 5a) showed waking up, brushing teeth and reading a book as sample projects. On the back page of the placemat were detailed instructions on how to attach the motor to the cardboard using tape and how to use the light sensor to build interactive projects.

The students continued to work in their respective groups. Since they had already used SmartMotors the previous day, they were able to dedicate more time to building. On the second day, the diversity of projects was evident. One project demonstrated how they put sunglasses on when they went outdoors. Another group built an artistic representation of the breakfast they had eaten that morning (Fig. 7a). Another group was inspired by the first group's idea of a sunny day and built a fan that turned on when the sun came out. Finally, the last group built a leg with two degrees of freedom to show how they played football in the morning (Fig. 7b). They used two SmartMotors to actuate two sections of the limb and coordinated to kick the ball. The overall complexity of the projects was significantly higher than that of the first day.



(a) Front page of day 2 placemat

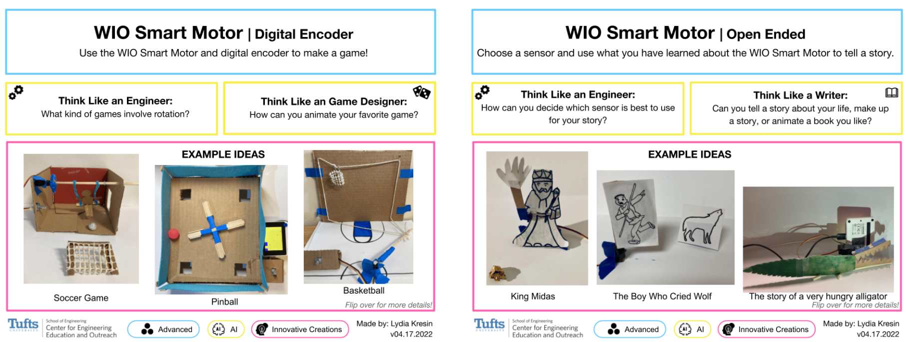
(b) Front page of day 3 placemat

Fig. 5: Front page of placemats for day 2 and 3

5.3 Day 3: Use the Wio SmartMotor and tilt sensor to make something related to the environment.

For the third activity, we asked the students to simulate an activity relating to the environment. The placemat (Fig. 5b) showed examples of the sun setting down behind the mountains, a telescope showing different moon phases, and a gate on a water dam moving up and down. The back page showed detailed instructions on how cardboard can be used to create complex structures.

Inspired by the sun setting example, one of the groups added the moon on the same shaft and demonstrated how when the earth tilts, the sun sets on one side, and the moon rises on the other. Another group wanted to bring attention to the issue of deforestation. They built a tree trunk and attached a cardboard axe to the motor shaft, which swiveled around and cut the tree trunk in half. They also wanted to use another motor to lift the tree back up to extend the message that deforestation should be stopped, but they needed more time to complete it. The third group built a windmill to bring up the topic of renewable energy. This group wanted the motor to move continuously; however, the servo could only sweep between 0 and 180 degrees (Fig. 7c). The final group built an assistive device to push the trash into a trash can. During this activity, the students worked on a wide range of project ideas meaningful to them and were able to get their message across using the SmartMotors.



(a) Front page of day 4 placemat (b) Front page of day 5 placemat

Fig. 6: Front page of placemats for day 4 and 5

5.4 Day 4: Use the Wio SmartMotor and digital encoder to make a game!

The prompt for the fourth day was to build a game using a digital encoder. The digital encoder is coded to work as a rotation sensor. The examples on placemat (Fig. 6a) showed a game of soccer, pinball game, and a basketball with a movable hoop. The back page showed how to build a sliding and pivoting mechanisms with string and pins.

The students were very excited to build the games and each pitched several ideas to their groups. Only two groups were able to complete their projects on time. One of the groups made a goalkeeper game, in which the objective for one player was to score a goal and for the other to move the goalie, controlled by the SmartMotor. Another team build an air hockey-type game with two controllers. The other teams who were not able to complete their projects cited lack of proper cardboard and glue guns as their reasons. They also indicated that they did not have enough time to realize their projects. It was noted that the groups who could not complete their projects had ambitious project ideas.

5.5 Day 5: Choose a sensor and use what you have learned about Wio SmartMotor to tell a story

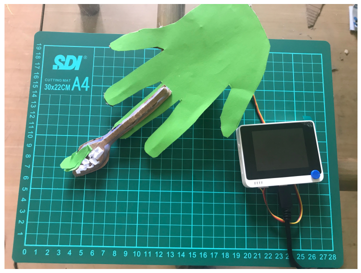
On the final day of the workshop, the students were asked to brainstorm in their groups a story they wanted to share with the larger group through SmartMotors. They were free to use a sensor of their choice. The examples on the placemat (Fig. 6b) showed classic children's stories, such as King Midas and The Boy Who Cried Wolf. The back page of the placemat showed all the materials they could use in the project. It also informed how they could use a linear regression model instead of a categorization model on the training data collected with the SmartMotors.

One of the groups built a project based on their own story involving a devil, monster, and shields, in which, interestingly, the main character lost the final battle. Another group shared the story of a woodcutter and an angel. In short, the angel who lives in a lake is delighted by the honesty of the woodcutter and rewards him with gold and silver axes, in addition to his iron axe that had fallen in the lake. The group attached the angel to the motor to mimic her rising from the lake surface with the different axes as they told the story. The third group retold the story of "This Ends With Us," with figures attached to two motors that swiveled and turned around to demonstrate how the events unfolded and the characters moved on with their lives (Fig. 7d). Finally, the last group told a miner's story who mined a diamond using a pick axe.

5.6 Summary

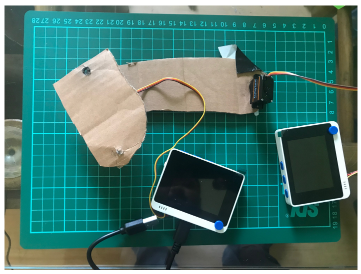
In this 5-day workshop, we observed that SmartMotors enable students to construct unique and creative projects. The students generated all the project ideas based on the prompts from the placemats. The facilitator asked questions during the build to encourage discussion and critical thinking. The availability of different sensors allowed them to combine different actions to trigger motor movements. Since the students were all new to the robotics and engineering design process, there was a lack of solution diversity on their first project. However, the primary goal of the first day of the workshop - to teach them how to use SmartMotors - was accomplished.

Beginning on the second day, we saw the students pushing the limits of materials to develop exciting project ideas. The students demonstrated outside-the-box thinking, from modifying the example on the placemat to using two motors to actuate different leg joints. Throughout the workshop, students worked in teams and challenged each other to build sophisticated projects. Some students focused on mechanical movements, while others focused on stories they wanted to share. One of the groups was focused more on the design and aesthetics part of the project, which was evident by how meticulously they built and decorated

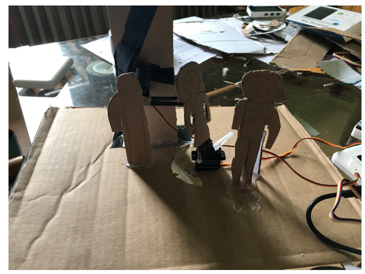


(a) Sample 1

(c) Sample 3



(b) Sample 2



(d) Sample 4

Fig. 7: Sample student projects from the workshop

their projects. Advanced system features were introduced to groups that were already comfortable with SmartMotors. On the final day, all students demonstrated creativity and imagination by telling a story through projects built using cardboard and the SmartMotor system.

We envision SmartMotors as a tool to lower the barriers of entry to robotics for beginners and students with limited access to computers, and the students' thinking about the features and further enhancements is an essential step in the direction of guiding students to become agents of creation than just consumers of technology [20]. The students encountered and highlighted some of the system's limitations - including the lack of continuous motors and the inability to control multiple motors at once. These issues can be opportunities to let the students explore more independently and creatively using the tools. Some issues, like the lack of speed control, can be easily solved by swapping the standard servo with a continuous servo. Issues of using multiple sensors or multiple motors can be solved by editing the code, which can be found in our website. However, the barriers of cost of the Wio Terminal based SmartMotors can only be lowered by either building a ecosystem where teachers and advanced students can build their own SmartMotors using the tools they already have, or building a cheaper version of SmartMotors. We have guides to help teachers and students to assist in this process in our website [16].

6 Conclusion

In this workshop, we demonstrated that students without prior experience in robotics can quickly build meaningful projects using SmartMotors. They may take some time to get comfortable with the new system [21], but with regular engagement they can learn how to navigate the system. The carefully designed activities can teach important robotics concepts, such as sensing, processing, and actuation, as well as the ideas of data collection and training. The use of placemats meant that minimum teacher intervention was required. The workshop demonstrated that students can move independently through the processes of discovery and self-exploration and that teachers without prior robotics experience can run these activities effectively.

Through SmartMotors and the corresponding activities outlined in placemats, we can engage users to think creatively and critically. The progression of complexity of the students' projects throughout the five-day workshop demonstrated that the SmartMotor system is adaptable to users with different levels of comfort with technology and robotics. SmartMotors also enabled users to meaningfully interact and learn from one another. The next step in the development of the system is to connect these activities to curricula and standards [22] for teachers, testing them in workshops in a variety of educational contexts. This version of SmartMotors uses Wio Terminal and the cost can be prohibiting for many users. The learning from this workshop will be used to design an accessible custom SmartMotors.

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