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Open-source Robotics for Academics: A Platform that Grows with the User

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Dr. Carlotta A. Berry is a professor, author, researcher, mentor, role model, prolific speaker, and a STEM trailblazer. In her efforts to increase the number of women and historically marginalized and minoritized students earning degrees in computer science, computer, electrical, and software engineering at her university, she co-founded the Rose Building Undergraduate Diversity professional development, networking, and scholarship program in 2008. Since its inception, there have been approximately 40 graduates and the number of women at the university has increased to 25%. In 2020, to achieve her mission to diversify STEM by bringing robotics to people and bringing people to robotics, she launched her business, NoireSTEMinist educational consulting. She also co-founded Black In Engineering and Black In Robotics to promote diversity, equity, inclusion and justice in STEM. Her innovative strategies to normalize seeing Black women in STEM including performing robot hip hop slam poetry, writing Black STEM Romance novels, conducting robotics workshops, creating open-source robots, sharing Black STEM digital AI art, and using social media to educate the world about engineering and robotics have proven to be groundbreaking and successful. One of her proudest accomplishments was receiving FIRST Robotics Competition volunteer of the year award for being a judge, judge advisor, and chair of regional and district planning committees for over a decade. This is second only to serving as co-leader of her daughter's Girl Scout troop and then mentoring those same girls on the Gamer Girlz FIRST Lego League and VEX robotics team. Through her innovative work in engineering education and STEM outreach, she has appeared in several print and digital media including Forbes, Black Enterprise, New York Times, and CBS News. She has also been recognized with several national awards including the American Society of Engineering Education (ASEE) fellow, ASEE Electrical and Computer Engineering Division Distinguished Engineering Educator, Grace Hopper Celebration Educational Innovation Abie Award, Institute of Electrical and Electronic Engineers Undergraduate Teaching Award, Indiana Business Journal Women of Influence, and Society of Women Engineers Distinguished Engineering Educator.

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Abstract

Robotics is an ideal tool for illustrating connections between multiple disciplines such as computer science, electrical, mechanical engineering, and social science. It is also a wonderful way to get young people interested in, involved in, and excited about the possibilities of science, technology, engineering, and mathematics (STEM). However, some challenges may limit the ability of some diverse or resource-limited communities from being able to access the benefits of robotics education. These barriers include the cost of educational robotics platforms and the lack of a knowledge base for novice educators to access.

Open-source robotics builds on the principles of open-source hardware and software. They both encourage publicly available models that afford collaboration through modification, making, selling, improvement, and distribution. This represents a shift in the traditional method that academics use for research and publishing but a necessary one to increase diversity, equity, inclusion, and justice in STEM. By not restricting access to work behind journal paywalls or conference fees, communities with limited resources can still benefit from them.

The "Robotics for the Streets" initiative was implemented in 2022 through the generous support of the Open-Source Hardware Association and Sloan Foundation to diversify STEM by using open-source robotics to increase access to and visibility of STEM technology. There was also a goal to illustrate to academics how to use open-source robotics to support their teaching, service, and professional development goals.

This paper describes the design and modifications of an open-source robotics platform, Flower∞Bots to increase access and inclusion in STEM and aid academics in professional development goals. The open-source robots described here are comprised of half 3D printed parts and half commercially available off-the-shelf parts. All the Computer-Aided Design (CAD) files, printer files, code, and videos for these robots are available online on YouTube, GitHub, HacksterIO, and Instructables. In the past, the open-source robot platforms, Flower∞Bots, have been used by organizations such as Black in Robotics, Girl Scouts, and Boys and Girls Club as well as university professors, graduate students, undergraduate students, K-12 teachers, K-12 students, and STEM enthusiasts around the world. It will be shown that the modularity of the Flower∞Bots make it suitable for a variety of applications as well as users with varying expertise.

1. Introduction

Robots are an ideal tool for recruiting diverse populations to STEM due to the multidisciplinary intersections that afford a variety of entry points. For example, robots can illustrate connections between electronics, kinematics, mechatronics, controls, programming, arts, and more. The flexibility of robotics means that it can be taught at a variety of levels to meet the diversity of needs, skill sets, applications, and prerequisite knowledge of the user. For example, a K-5 teacher can use a robot to teach graphical programming. A 6-12 teacher could use that same robot to teach introductory electronics. First-year college students can learn object-oriented software development while graduate students implement behavior-based control, human-robot interaction, or machine learning algorithms. In addition, academics can go beyond teaching and use robotics for service to recruit young people to STEM and undergraduate or graduate research.

The low-cost, open-source, modular platform described here, Flower∞Bots, opens the possibilities for populations that may not have been able to engage in such activities before. Flower∞Bots are so named because they grow with the user. The infinity symbol in the middle of the name indicates that the open-source nature of the robots affords an infinite number of learning and growth opportunities. There are three robots in the Flower∞Bots community including Lily∞Bot, Daisy∞Bot, and Rosie∞Bot. The three levels represent introductory, intermediate, and advanced robotic platforms, respectively. This paper will focus primarily on the Lily∞Bot and Daisy∞Bot. Lily∞Bot has the modularity and flexibility to be programmed graphically and text based with MicroBit, Arduino Uno, and Raspberry Pi Pico W. The programming languages include Python, MicroPython, Arduino Sketch, and MakeCode. The current iteration of the Daisy∞Bot has the Arduino Mega and is programmed in Arduino Sketch. The variety of controllers and power modules to increase the complexity of the platform has the educational benefit of enabling the learner to use familiarity with the hardware platform and language to scaffold their knowledge.

This paper describes the design of the robots and the subsequent modifications after feedback from participants in a user study. The participants had a diversity of backgrounds and skill sets from K-12 to collegiate and makers. This open-source, low-cost modular robot platform presented here attempts to increase access, reduce cost, and share knowledge in engineering education with the creation of a modular open-source robot that can be modified to meet the needs of the user.

Additionally, including comprehensive tutorials, guides, and instructional resources empowers educators, researchers, and enthusiasts to build, program, and use the robot in the most appropriate way for their needs. Since the entire project follows the principles of open-source hardware, it fosters collaboration and knowledge sharing, thereby enabling a global community of learners and innovators.

Finally, there will be a discussion on how open-source robotics, combined with modularity and accessible educational materials, revolutionizes robotics education by providing a customizable, hands-on learning experience to serve as a valuable resource for diverse communities, fostering a passion for technology, and enhancing STEM education at all levels.

2. Background

2.1 Challenges

Using robotics in a classroom is a great resource for multiple levels of education. Matarić [1] found that there were benefits to having robotics education for all ages. Robots are a great tool for teaching science and engineering and creating a pipeline into STEM. However, some challenges include teachers having limited time, lack of age-appropriate teaching materials, and textbooks appropriate for undergraduates. Although there is great benefit in teaching robotics with hands-on activities, some platforms have limited I/O capabilities and cannot take external input from sensors. Thus, the need for a platform that can be modified to meet the users' needs. This is the need that the Flower∞Bots platform attempts to address.

2.1 State of Robotics Education

Esposito [4] presented the results of an online faculty survey on the state of robotics education. The primary focus was degree programs, introductory robotics courses, and educational resources. Some results indicated that teaching robotics to a diversity of student and instructor backgrounds could be a challenge. The survey indicated there were thirty-four different commercially available platforms that instructors used for their introductory robotics courses. Most of the platforms were under $1000 but there was still a common theme. Instructors desired low-cost, small-form-factor, high-quality articulated manipulators. They also requested that the platform integrate with an open application-program interface from computing environments such as C, ROS (Robot Operating System), or MATLAB. Although this paper focuses on a wheeled mobile robot, some of these characteristics would still stand. One-quarter of the respondents stated that they taught their course with an articulated manipulator while another one-quarter used ground-based indoor mobile robots.

2.3 Unified Robotics Curriculum

Berry et al. [2] proposed that the benefits of robotics to all ages could be improved with the creation of a unified curriculum that translates to multiple backgrounds. The authors conclude that having a standard framework for a robotics curriculum may provide a means to assess the effectiveness and value of robotics education. This curriculum would naturally translate into hands-on learning activities to enhance understanding. Vanderborght [3] stated that although hardware can be hard, it can be completed with multidisciplinary teams of engineers, designers, etc. This process was made easier due to the advent of 3-D printing, electronics, laser cutting, and computing devices. Some of the benefits of open-source robotics were quick improvement and fabrication without long-term commitment or cost. This approach was used for the Flower∞Bots to quickly deploy updates and make improvements for assembly and use.

2.4 Open-Source Robots

Miller-Klugmann et al. [5] developed a small, affordable, open-source educational robot using commercial off-the-shelf parts. There was also flexibility to scale up to programming with a Raspberry Pi Zero with a GPIO library. Although the discussion of this final platform presented the idea of adding more sensors, there does not appear to be any goal of increasing modularity or scalability with the addition of more controllers and battery packs. This was the primary distinction between the Miller-Klugmann platform and the Flower∞Bots. Berry et al. [6] stated that open-source robotics is novel, unique, and innovative. One of the primary reasons is that it encourages diverse voices and perspectives to contribute to the creation and improvement of robotics education and technology. They also concluded the open-source robots platform enables resource-limited academics to engage in service, teaching, and research.

3. Evaluation of the Platform

After the initial development of the Flower∞Bots platform, the kits were shipped to K-12 teachers, university professors, engineers, scientists, makers, and students. There were twenty-nine academics including high school teachers and college professors, ten practitioners, four graduate students, and one post-doc. They were used in high school classes, engineering and non-engineering college courses, summer camps, and by individuals. To ensure that there was a diversity of skillsets and backgrounds, the evaluators were recruited from Black in Robotics, Black in Engineering, Women in Robotics, NSBE, AA-roboticists, AA-PHD-CS, Future of Mechatronics and Robotics Engineering Education, and social media.

Twenty-three evaluators received the smaller Lily∞Bot with Arduino for novice users. Twenty-one evaluators received the slightly larger Daisy Bot with Arduino Mega for intermediate users. The evaluators were asked to complete several tasks including assembling the robot, wiring electronics, programming sensors, and creating robot motion and obstacle avoidance behaviors. They then completed a survey about the experience and based on the feedback, the robot platform went through multiple updates and redesigns (see appendix). The most prevalent feedback was the request for the option for more types of controllers and more learning resources. Thus, this paper discusses how those modifications enhance the platform and engineering education.

4. Features of the Flower∞Bots

This section will describe the robot updates based on user evaluation. Specifically, the addition of the modular capabilities for the Flower∞Bots, such as controller and battery modules allow the user to keep the same robot base even as it grows in capability or intelligence. Central to the project's innovation is the seamless interchangeability of microcontrollers, supporting Arduino, Raspberry Pi, and MicroBit controllers, with more to come later. This flexibility ensures the accessibility of the robots across various educational levels, from primary education to advanced research. This flexibility affords graphical programming as well as programming in Arduino Sketch or MicroPython. It also allows for increased levels of difficulty with respect to sensing capabilities, control algorithms, and robot behaviors. These features emphasize the robots' adaptability and ease of customization to grow with the user.

4.1 Microcontroller Modularity

There were many mechanical improvements from the previous design. This includes making the top and bottom of the chassis modular to accommodate different microcontrollers and batteries, improving the traction of the wheels, and redesigning the sensor attachments. The top and bottom modularity exploited the ability to use different microprocessors on the same chassis. The change in the motor mounts came after multiple people reported on the survey that the “wheels aren’t getting enough traction”. Based on that, the new design allowed for better contact between the wheel and the ground, which improved the movement of the robot. Finally, the new design of the sensor attachment allows for easier and faster exchange of sensors and other peripherals.

There are three Flower∞Bots models, Lily∞Bot, Daisy∞Bot, and Rosie∞Bot. They were designed to be compatible with multiple microprocessors. The differences between them are size, sensors, peripherals, and power requirements. The robot sizes are 6”, 9”, and 12” in diameter, respectively. The compatible microprocessors align with the purpose of each model, novice, intermediate, and advanced, respectively. Lily∞Bot is compatible with simpler and easier to use microcontrollers for novice users. Daisy∞Bot was for intermediate users with a larger footprint to hold more sensors. Finally, the largest robot, Rosie∞Bot was designed for advanced behaviors and research including higher processing power and more sensors and peripherals. Table 1 provides a summary of the recommended controllers used on the respective robots by skill level.

Table 1: Summary of the three levels of Flower∞Bots and the associated microcontrollers

Level	**Robot**	**Microcontrollers**
Novice	Lily∞Bot	MicroBit, Arduino Uno, Raspberry Pi Pico W
Intermediate	Daisy∞Bot	Arduino Mega, Arduino Nano
Advanced	Rosie∞Bot	Arduino Giga R1 W, Raspberry Pi

In the previous design, it was possible to use different microcontrollers, but it was difficult, costly, and time-consuming to switch the microprocessor. A new top chassis was printed every time the microprocessor was changed which required moving all the electronics to the new chassis and reattaching it to the rest of the robot. A college professor who received the original Lily∞Bot said that “to support more advanced research, it would be useful to design the robot to support multiple different processors.” The new design has a top module that can be easily switched on without replacing any other parts of the robot. Figure 1 shows the top module on the robot for the MicroBit and Arduino Uno. As can be seen, it is quite simple to replace the microprocessor with a new one and the rest of the chassis can be reused. Only two screws were required to take the module on and off. Importantly, the wiring on the breadboard can remain intact, saving a significant amount of time. This modular design enables users to quickly switch to the most suitable processor for their specific application. The top module has a rectangular opening where the microprocessor holder is secured. As seen in Figure 1, the microprocessor attachment is held by two screws that are easily removed to replace the microprocessor.

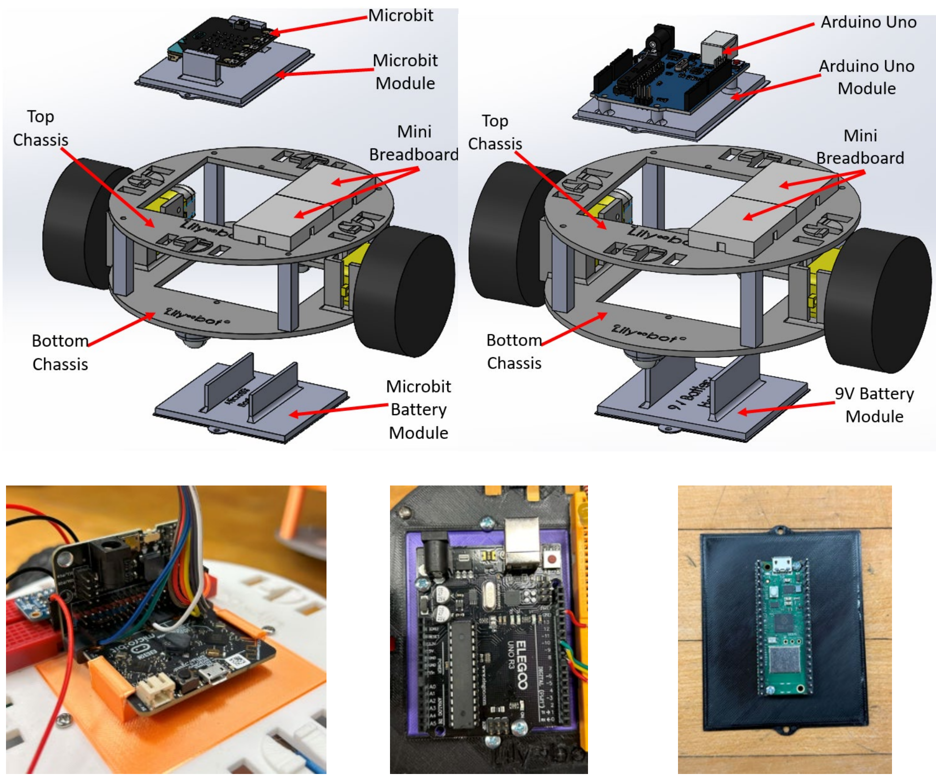

Figure 1: Exploded view of Lily Bot with different controllers and actual modules including MicroBit, Arduino Uno, and Raspberry PI Pico W with levels of difficulty from left to right.

4.2 Microcontroller Power Requirements

A challenge of using multiple microcontrollers is they each require a different power supply. This includes 9V batteries, 4 AA batteries, 6 AA batteries, and 2 AAA batteries (see Figure 2). Sometimes it was required to have two different battery packs. For example, when the

Daisy∞Bot was driven with the PlayStation controller for a high school engineering design competition, there was not enough power. The Arduino Uno could not run the robot motors, sonar, and PlayStation controller so the robot had a 9V battery pack and 4 AA battery pack. The 4 AA battery pack was dedicated power to run the motors while everything else was on the 9V battery back (see Figure 3). This situation is the prime benefit of using a modular 3D printed robot. When a last-minute change is necessary, it is as simple as creating the design in TinkerCad or SolidWorks, printing it out, assembling and testing it. The old chassis had to be completely reassembled to change the battery type. Also, within the same battery type, it was hard to switch when the battery died. A high school teacher reported that "a simpler 9V case would also be appreciated (like just a connector) as the enclosed case made it very difficult to slip the battery in and out." Thus, a new battery attachment was designed that allows the batteries to be easily extracted from the bottom (Figure 1) and switched to different modules, as can be seen in Figure 2.

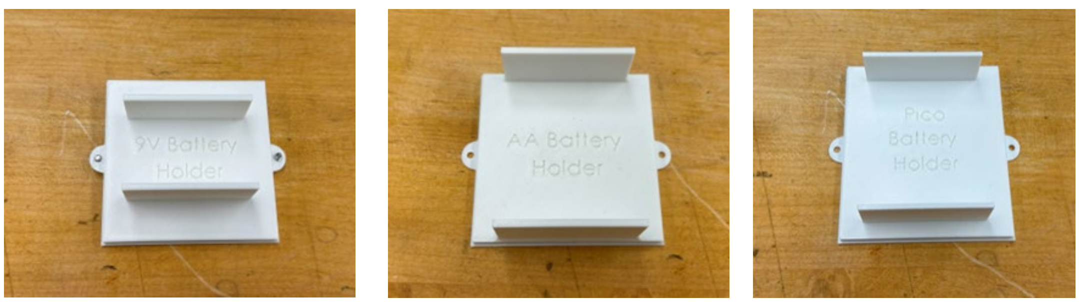

Figure 2: A sample of the battery modules used on the Flower∞Bots for various microcontrollers.

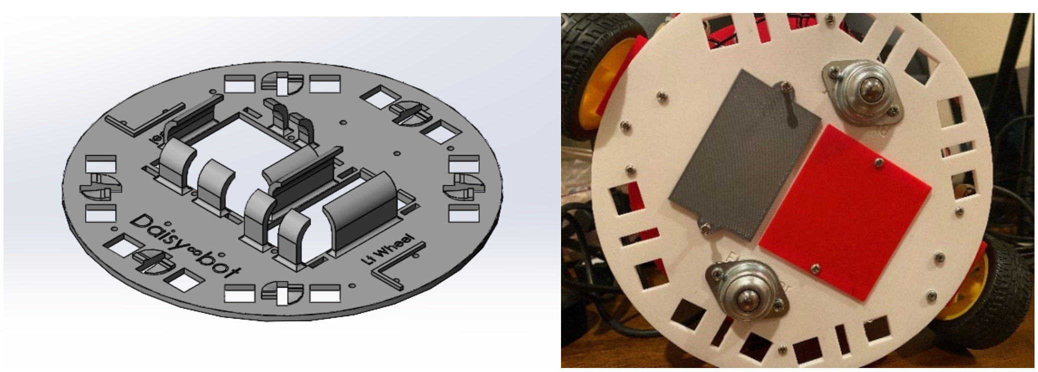

Figure 3: A Daisy∞Bot designed with two power sources for motors, sensors, and remote control.

4.3 Increased Motor Traction

Previously, reviewers identified a traction issue with the Flower∞Bots. This problem came from one of the motorized wheels not maintaining contact with the ground because the caster wheels were slightly lower. The root cause was a gap between the bottom chassis and the motor mount, a variance introduced by 3D printing tolerances, as can be seen in Figure 4. To address this issue, two solutions were devised.

Solution A involved modifying the bottom chassis by making it slightly thinner where the motor attachment is situated, as can be seen in Figure 4. This adjustment allowed the motorized wheels to be lower than the caster wheels, improving the traction. However, this solution came with a drawback: it increased the rocking motion of the robot, making it more challenging to control.

Thus, solution B was designed. As can be seen in Figure 4, solution B consists of merging the motor mount with the chassis by eliminating the gap that was causing the issue. This allowed all robots to have consistent traction.

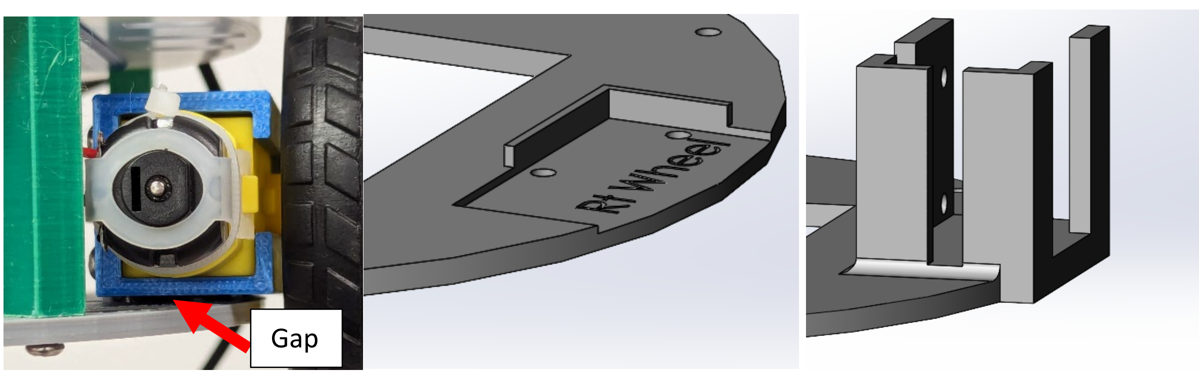

Figure 4: (Left) Initial problem with traction due to the gap shown. (Middle) Solution A for the short-term allowing more traction but more rocking. (Right) Solution B eliminated the gap.

It's important to note the reason behind having two solutions. Solution A was meant as a short-term fix, using the same motor mounts. Solution B was implemented as a long-term solution for new robots, providing a more permanent fix by integrating the motor mount with the chassis.

5. Learning Resources

To aid educators with using the Flower∞Bots to meet their professional goals, the authors created various learning resources. These included blog posts on a professional website, videos on YouTube, code, Fritzing, 3D printer files on GitHub, and tutorials on HacksterIO and Instructables. Examples of guidance for wiring electronics are given in Figure 5. This example shows the wiring diagram for an obstacle avoidance robot programmed in MicroPython using the Raspberry PI Pico W and programmed in a graphical language. The robot could be programmed graphically by using software similar to Scratch, Blockly, or Makey. There are several graphical programming sites for Arduino. It also demonstrates PlayStation control using an Arduino Mega on the Daisy∞Bot. The resources also provide the code to aid the user in programming the robot in the language of their choice as shown in Figure 6.

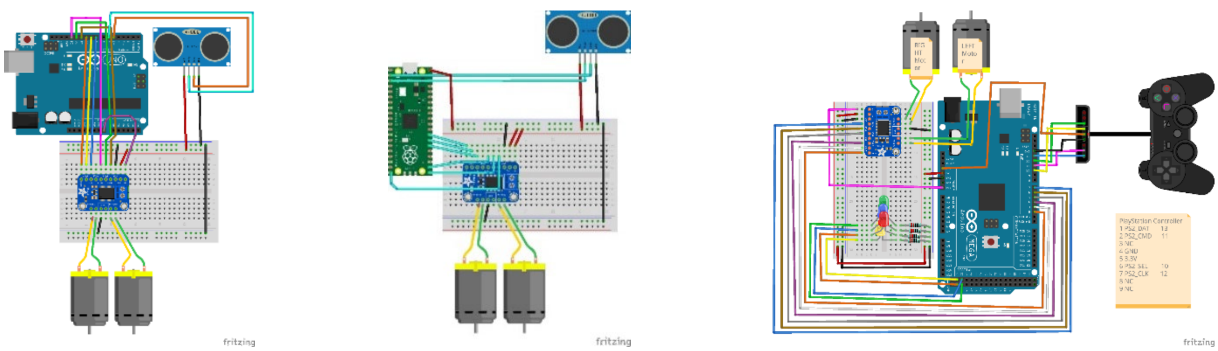

Figure 5: Lily∞Bot wiring diagram for obstacle avoidance using sonar sensor on Arduino Uno and Raspberry Pi Pico W, Daisy∞Bot wiring diagram for PlayStation control.

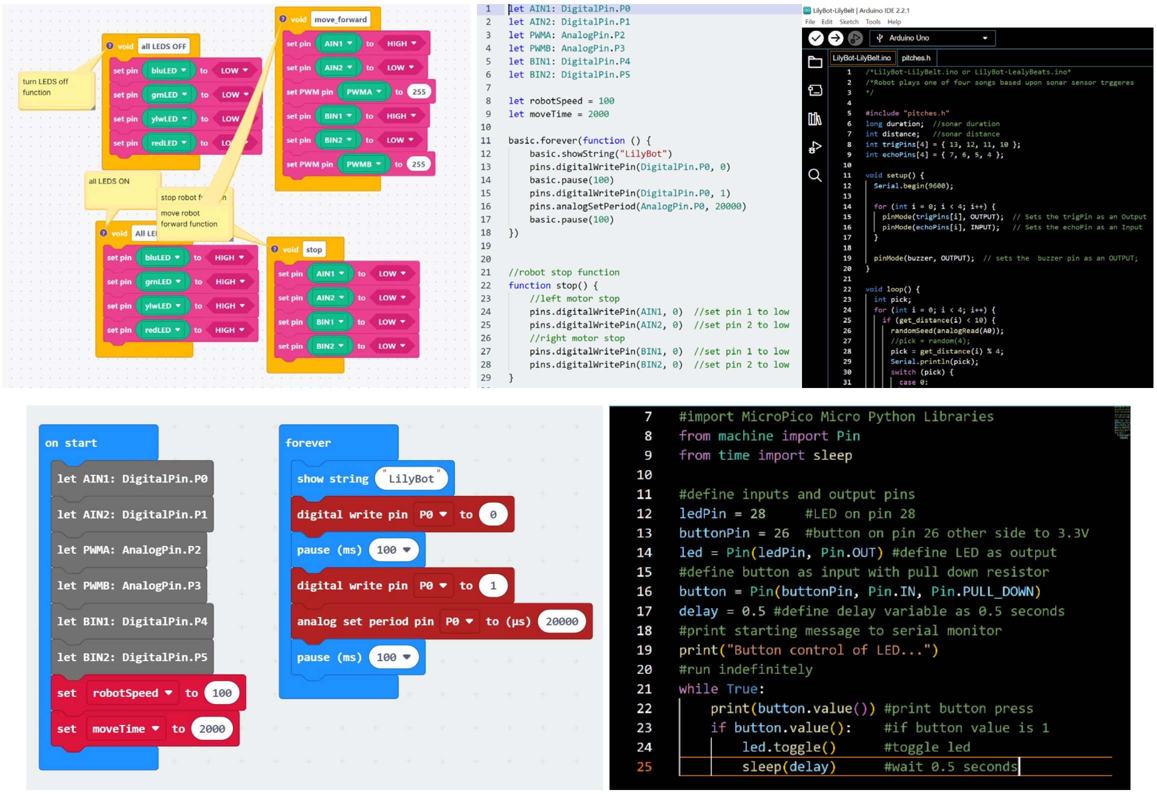

Figure 6: Examples of Graphical for Arduino, Graphical for MicroBit, MakeCode for MicroBit, Arduino Sketch, and MicroPython code used to program the Flower∞Bots.

The authors have been able to show proof of concept with various robotics applications using a diversity of controllers. Table 2 summarizes these applications based on skill level as well as a robotic platform. These concepts showed the capabilities of the various controls regarding digital and analog IO, remote, and autonomous control.

Table 2: Lily∞Bot Learning Activities

Level of Difficulty	Activity
Novice	Assemble the robot
Novice	Wire and program the robot to move with the motors
Novice	Program robot to drive in a circle, square, and/or figure eight
Intermediate	Wire and create a light pattern with LEDs
Intermediate	Wire and program button to turn on LEDs or move the robot
Intermediate	Wire and program buzzer to play music on the robot

Advanced	Wire a photoresistor and program the robot to track light
Advanced	Wire an ultrasonic distance sensor and program the robot to track and avoid objects

6. Conclusion and Future Work

In conclusion, this paper presents an innovative, novel open-source robotics platform to aid engineering educators in reaching their professional development goals. It is modifiable to be used with novice to advanced users with respect to service, teaching, and research. The next steps will be to create more advanced proofs of concept and learning activities on the advanced platforms (Daisy∞Bot, Rosie∞Bot). These will include using more controllers (Arduino Nano, Arduino Giga R1 W, Raspberry PI), more peripherals such as Arduino Camera, encoders, and grippers, as well as implementing advanced behaviors like swarming, SLAM, Machine Learning, etc. These resources will then be shared with academics and makers through tutorials, workshops, and technical presentations.

7. Acknowledgements

The authors would like to thank the Open-Source Hardware Association and Sloan Foundation for their generous support of this work. This project is [OSHW] XXXX | Certified open-source hardware | oshwa.org/cert.

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Appendix

Open-Source Hardware Platform (Flower∞Bots) Survey

1	On a scale of 1 to 5 with 5 being the most proficient, how familiar are you with robotics?
2	On a scale of 1 to 5 with 5 being the most proficient, how familiar are you with programming?
3	On a scale of 1 to 5 with 5 being the most proficient, how familiar are you with electronics?
4	What type of robot did you receive?
5	What resources did you use when evaluating the platform?
6	Which resource did you find the most useful during your evaluation?
7	On a scale of 1 to 5, with 5 being extremely easy, how difficult was it to build the robot?
8	Please provide any additional feedback about the assembly process.
9	On a scale of 1 to 5, with 5 being extremely easy, how difficult was it to program the robot to move?
10	Please provide any additional feedback on programming the robot for motion control.
11	On a scale of 1 to 5 with 5 being the most difficult, how difficult was it to attach the LEDs to the robot?
12	On a scale of 1 to 5 with 5 being the most difficult, how easy was it to program the LEDS on the robot?
13	Provide any additional feedback regarding using LEDs on the Flower∞Bot.
14	On a scale of 1 to 5 with 5 being the most difficult, how difficult was it to attach the sonar to the robot?
15	On a scale of 1 to 5 with 5 being the most difficult, how difficult was it to program the sonar sensor?
16	Provide any additional feedback regarding using Sonar on the Flower∞Bot.
17	On a scale of 1 to 5 with 5 being the most difficult, how difficult was it to attach the IR sensor to the robot?
18	On a scale of 1 to 5 with 5 being the most difficult, how difficult was it to program the IR sensor?
19	Provide any additional feedback regarding using the IR sensor on the Flower∞Bot.
20	On a scale of 1 to 5 with 5 being the most difficult, how difficult was it to attach the photoresistor to the robot?
21	On a scale of 1 to 5 with 5 being the most difficult, how difficult was it to program the photoresistors?
22	Provide any additional feedback regarding using the photoresistor sensor on the Flower∞Bot.
23	On a scale of 1 to 5 with 5 being the most difficult, how difficult was it to program the buzzer?
24	On a scale of 1 to 5 with 5 being the most difficult, how difficult was it to program the buzzer?
25	Provide any additional feedback regarding using the buzzer on the Flower∞Bot.

26	One goal of this work is for the Flower∞Bots to be used for K-12 outreach to get more young people interested in and excited about STEM. On a scale of 1 to 5, with 5 being very well, how well do you think these robots meet this mission?
27	Please provide additional feedback on using the Flower∞Bots for introducing young people to robotics and STEM.
28	One goal of this work is for the Flower∞Bots to be used by academics for teaching electronics, design, and robotics to high school or college first-year students. On a scale of 1 to 5 with 5 being very well, how well do you think these robots meet this mission?
29	Please provide additional feedback on using the Flower∞Bots for teaching high school or introductory robotics or engineering courses.
30	One goal of this work is for the Flower∞Bots to be used by academics for advanced courses or conducting research in robotics. On a scale of 1 to 5 with 5 being very well, how well do you think these robots meet this mission?
31	Please provide additional thoughts on using the Flower∞Bots for teaching advanced courses or research in robotics?
32	Race/Ethnicity
33	Gender Identity
34	Occupation
35	Industry
36	Please use this space to share any additional thoughts.