Toward a socially responsible computing education through collaborative robotics

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Abstract. This project provides a generalizable framework for robotics education aimed at adolescents. The bulk of existing research and real-world implementation of robotics education, and computer science education broadly, is focused on increasing participation in STEM without a critical look into the details of doing so—namely, questioning the methods for increasing participation and reconsidering what counts as participating in STEM. The downstream effect of this difference is that the onus is put on students to bridge any knowledge gap they may have, reducing motivation and increasing the barrier to entry. Through this project, we propose an alternate approach, one that attempts to meet students at their existing abilities and interests, rather than having students conform to high-level technical expectations. We use these considerations as a jumping off point for developing a critical STEM education plan, with two aims in mind: 1) how can we, as STEM educators, serve students taking into account different learning styles, abilities and backgrounds?, and 2) contribute to the growing field of socially responsible computer science education by incorporating the arts into robotics education? The purpose of our proposed lesson plans is not to replace STEM education, but to serve as a supplement to it, one that can build excitement about these topics and encourage participation through multiple and varied avenues.

Keywords: robotics education · socially responsible computing · adolescents · funds of knowledge.

1 Introduction

Computer science often positions itself as an objective and neutral discipline. However, contrary to this traditional viewpoint, computing education and the technology that develops as a result, cannot be separated from its social context. As former Google engineers Alex Hanna, Timnit Gebru and others have pointed out, computer science and engineering does not happen in a vacuum, and the individual biases and forms of oppression that emerge reflect institutional problems (Yadav et al., 2022). Thus, addressing problems of oppression and encouraging equitable access within STEM and STEM education, requires changes at the institutional level. In the context of computer science education, students must be equipped with not only technical skills, but a framework for contextualizing technology within their communities rather than as isolated actors. Computing education has begun to integrate more diverse methods to broaden participation, but if we are to fix internal injustices, we need to go beyond increasing access. The main aim of this study is to create a socially-oriented approach to robotics education by humanizing its pedagogy, centering students in curriculum development, encouraging critical thinking, and developing students' understanding of their own responsibilities within their immediate communities and society at large.

The need for a more diverse robotics education exists among all levels of learners, but the focus of this study is limited to adolescents for several reasons. First, adolescents are generally able to evaluate context at several levels, compared to younger children, and thus have an increased ability for critically examining technology. Second, adolescence is the period when individuals begin to develop a sense of social altruism and awareness of their decisions' impact on others (Berndt, 1982 and Crone, 2013).

The approach for developing the educational framework and lesson plans in this study is, in part, inspired by the funds of knowledge approach in education, which puts forth the idea that students already have developed knowledge and skills based on their background, lived experiences, privileges, etc. (Gonzálex et al., 2006, Moll et. al, 1992). Findings from Salac et al. demonstrate that participants leverage different aspects of sense-making based on their background and approach technical problems within the context of their existing knowledge and experience. Furthermore, by incorporating students' existing skills and experience, they found that the funds of knowledge approach could allow for introducing more technical concepts into learning without requiring formal training or prerequisite experience (Salac et al., 2023 and Svihla, et al., 2022). As a result, learners from marginalized groups can have different sources of experience and knowledge that "are often delegitimized in academic systems" (Salac et. al, 2023). The funds of knowledge approach allows students with minimal or no formal training in a given technology to contribute by bringing their skills and experiences to solving the problem. With this in mind, the key focus of this study was to improve upon the predominant framework that is focused only on broadening participation in adolescent STEM education, so that students from marginalized backgrounds may be equitably incorporated in the growing movement for socially responsible computing education (Salac et. al, 2023). Context is important not just for technical ability but also in how students approach learning.

2 Approach and methods

Building on prior literature and existing implementations of robotics education, this study aimed to create a scaffold for socially-responsible computing education that offers multiple entry points for engagement and contribution beyond purely technical. As stated earlier on, the basis of this educational study takes on a funds of knowledge approach. In application, this required developing a lesson plan that was both generalizable and applicable to the particular cohort of students being addressed.

2.1 Lesson Plan 1:

Using research from UC Berkeley Robot Hall of Science for inspiration, this lesson plan aims to broaden participation in robotics and computer science through an interdisciplinary project that brings together robotics, programming, hardware, collaboration and art. Students will assemble a mini-animal robot using the Hummingbird Robotics Kit. The detailed instructions for this lesson are included in the appendix and here. Successful implementation of this lesson plan includes incorporating the equitable strategies listed below.

Equitable strategies: Low barrier to entry (start with easy assignments, assume little/no familiarity), Encourage collaboration and tap into different funds of knowledge through group/pair-programming (students will work in small teams to create the code), Reduce imposter syndrome (build confidence early through successful programming, all students can see themselves as "real" computer scientists/roboticists), Everyone has something to show off. If there are some students not interested in the hardware/software component, there are other fun parts to contribute to–like design of the robot, crafting with different materials, etc.

2.2 Lesson Plan 2:

Inspired by the Child-Robot Theater studies of the Mind Music Machine group, formerly residing at Michigan Tech, we endeavor to introduce 5th grade students to problems in multirobot systems by inviting them into Professor Nora Ayanian's Automated Coordination of Teams (ACT) Lab on Brown's campus and introducing them to a number of the technologies in the Lab. The objective of this lesson plan is to further engage this cohort of students in the subjects of Robotics and specifically Coordinated Mobile Robotics by connecting them with the remote control drone, painting drone, and CrazySwarm technologies at the ACT Lab. The detailed instructions for this lesson are included in the appendix and here.

Equitable strategies: In a similar fashion to Lesson Plan 1, we will focus on low barriers to entry and engaging students across a variety of entry points. If students do not like the remote control operation of the drone, they can try coloring the canvas to paint collaboratively with the larger drone; if they don't like that activity, they can try to use block programming to program the CrazySwarm.

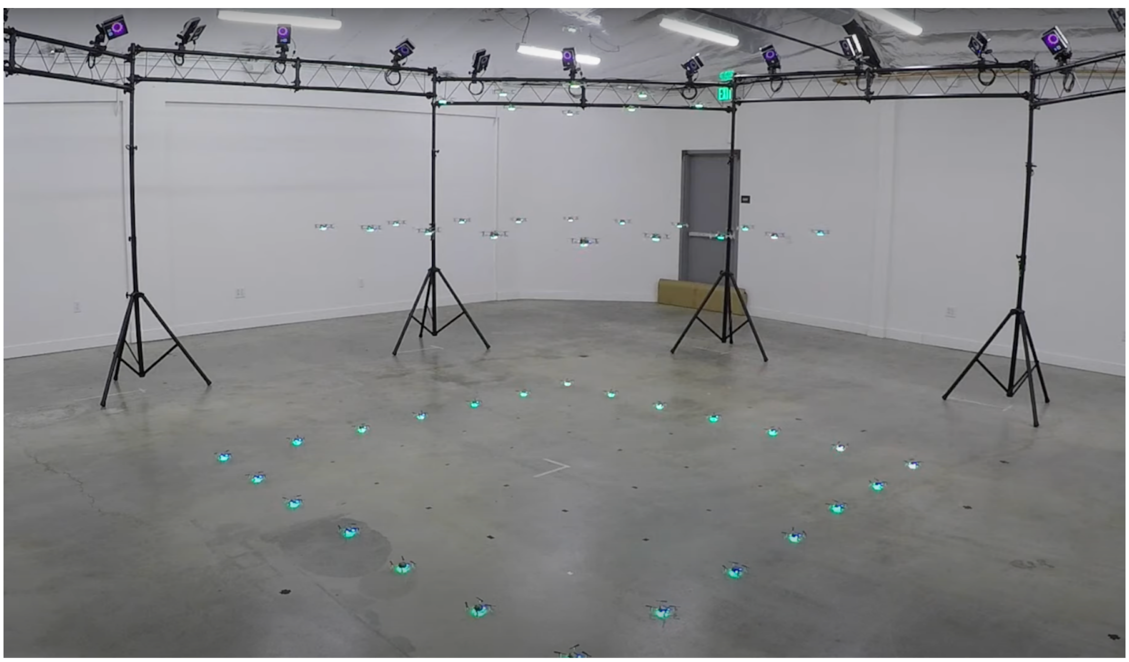

Fig. 1. CrazySwarm in action in the Automated Coordination of Teams (ACT) Lab. Image Source: https://www.youtube.com/watch?v=ezTayb76x9U

3 Implementation

The implementation phase of the project involved creating two to three lesson plans for adolescents, focusing on the integration of Coordinated Mobile Robots into classroom settings. These plans aimed to illustrate the challenges and possibilities of using multiple robots collaboratively. An ambitious aspect of the project was to demonstrate the connection between coordinated robot path planning and human movement through 3D modeling. The ultimate goal included the practical application of this curriculum in a 5th grade or lower school classroom in the Providence area, enhancing the project's real-world relevance and impact. The implementation of our project is scheduled to take place in Spring 2024.

4 Results and evaluation

The project's evaluation centers on measuring student curiosity about robotics and its application to learning about topics in Coordinated Mobile Robotics.

Table 1. Pre-Workshop Survey (rate on a scale of 1-5):

Questions	Perception of robotics	Curiosity	Future events
1.	How interested are you in Science, Technology, Engineering, and Math?	Have you ever wondered about the possibilities of Robots and what they can do?	Are you excited to learn how to build a Robot and to visit the ACT Robotics Lab at Brown?
2.	Do you have interest in the topics of Robotics and/or Computer Science?	Do you want to engage with Robots or Computer Science and learn skills in this area?	Can you see yourself working with Robots in the future?
3.	Do you see yourself as a scientist? Or could you see yourself BECOMING a scientist?	Based on your experience with Robots, do you have more questions you would like to study to get the answers to?	How likely are you to do personal research about Robotics or Computer Science, such as read a book or do an internet search?

Table 2. Post-Workshop Survey (rate on a scale of 1-5):

Questions	Perception of robotics	Curiosity	Future events
1.	After experiencing these Robotics lesson plans, how interested are you now in Science, Technology, Engineering, and Math?	After experiencing these Robotics lesson plans, do you wonder more about the possibilities of Robots and what they can do?	After experiencing these Robotics lesson plans, would you participate in a program that allowed you to explore Robotics and Computer Science further?
2.	After experiencing these Robotics lesson plans, how interested are you in the topics of Robotics and/or Computer Science?	After experiencing these Robotics lesson plans, do you want to engage with Robots or Computer Science and learn additional skills in this area?	After experiencing these Robotics lesson plans, can you see yourself working with Robots in the future?
3.	After experiencing these Robotics lesson plans, do you see yourself as a scientist? Or could you see yourself BECOMING a scientist?	Based on your new experiences with Robots, do you have more questions you would like to study to get the answers to?	After experiencing these Robotics lesson plans, how likely are you to do personal research about Robotics or Computer Science, such as read a book or do an internet search?

5 Strengths and weaknesses

The project's strengths reside in its culturally inclusive approach, embracing the range of backgrounds and experiences of students through a funds of knowledge methodology. This approach, paired with an interdisciplinary curriculum that blends bioinspiration, ethics, and art, offers an avenue for all learners to engage in creativity and critical thinking, making STEM education more accessible and engaging. Further, it challenges the notion that STEM, and robotics in particular, exists in a vacuum outside of the humanities and is able to be contextualized within the social context in which their practices are being implemented. However, the program's reliance on specialized resources and skilled instructors could limit its applicability in resource-constrained environments. A more defined mechanism for evaluating the long-term impact on students' interests, background and technical training in robotics is also necessary to fully assess the program's effectiveness.

6 Related work

This study aligns with current research emphasizing the importance of inclusive, socially responsible and contextually aware approaches to STEM and robotics education. Key references, such as Salac et. al. (2023) and Long and Magerko (2020) underscore the need for educational frameworks that recognize and utilize students' diverse backgrounds, experiences, and perceptions. The use of bioinspiration, ethics and robot art as focal points for engaging students in robotics, as discussed by Kube and Bonabeau (2000) and Anderson and Franks (2001), contributes to a more holistic and interdisciplinary approach to robotics education. The work of Yadav, Heath, and Hu (2022) further supports the pressing need for a justice-oriented curriculum that goes beyond mere participation, advocating for a humanizing pedagogy that respects and leverages students' existing sources of knowledge and cultural backgrounds. This project also echoes the findings of Barnes et al. (2020) and Yadav and Cooper (2017), who have explored creative robotics activities and their impact on fostering creativity in elementary and middle school students. Collectively, these works form a foundation for an education model that is not only technically sound but also socially and culturally conscious.

7 Ethical implications

The project, in navigating the intersection of robotics and adolescent education, raises several ethical considerations. It's imperative to address the risk of deepening socio-economic divides, as access to advanced technology and quality STEM education often correlates with economic status. Furthermore, culturally responsive pedagogy must be employed with sensitivity to avoid reinforcing stereotypes or biases. Ethical implications also extend to the portrayal of robots, ensuring they are not depicted in a way that unrealistically elevates their capabilities, which could lead to overdependence or unfounded fears among students. These considerations are crucial for fostering an ethically informed, equitable, and realistic understanding of robotics in education.

8 Summary

While there is rich and interesting research regarding socially responsible approaches to computing, the actual implementation of these approaches in classrooms is still in its infancy. Through our Robotics and Coordinated Mobile Robotics lesson plans, we extend the efforts of teams such as Salac, et al, and Barnes, et al, to invent novel methods of bringing STEM and Robotics education to adolescents through engaging classroom activities. In particular, we believe that the introduction of the Hummingbird Robotics Kits, and the connection between the groups of students and the members of the ACT Lab at Brown, will bring about a new appreciation for and interest in embracing STEM, CS, and Robotics, which we will measure in our before- and after-lesson surveys. We look forward to carrying out the lesson plans with live classrooms of students in Spring 2024.

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9 Appendix

9.1 Lesson plan 1

Lesson title: Mini animal-bot

Background: Based on research from the UC Berkeley Robot Hall of Science to broaden the participation in robotics and computer science, this lesson draws inspiration from two project plans from the Hummingbird Robotics kit.

Overview/Big ideas: The objective of this lesson plan is to engage late elementary to middle school students in a creative and approachable design and programming challenge. Students will build and design a mini bot that uses 2 “servos” to control its head.

Concepts: This lesson will teach students basic programming and get them familiar with building simple robots. Students will also have the opportunity to use craft materials to design the shape and appearance of their robot.

CS/Robotics Teaching Strategies: Group/pair-programming (students will work in small teams to create the code), debugging (students will work in their groups independently to debug their code/assembly, with instructors available if they get stuck).

Equitable strategies: Low barrier to entry (start with easy assignments, assume little/no familiarity), Reducing imposter syndrome (build confidence early through successfully programming, all students can see themselves as "real" computer scientists/roboticists), Everyone has something to show off. If there are some students not interested in the hardware/software component, there are other fun parts to contribute to–like design of the robot, crafting with different materials, etc.

What students will do: First, students will be shown pictures and videos of what can be accomplished to give inspiration and provide some excitement to do the project. The next part will be designing the actual robot. Students will be provided with the essential components of the cardboard pieces that constitute the body, with some parts of it left for them to create, brainstorming as groups what they want their robot to look like. The next part of the lesson will be to integrate the hardware into the robot and finally programming the robot to move it's head (left, right, up and down).

What students will accomplish/learn: As a team, students will have completed a personalized mini robot that is able to move its head along 2 axes.

<u>*Lesson—Part 1:*</u> Objectives: Introduce the activity, get students interested and give an overview of what the project will entail, what materials they will be working with. Ask the class a few questions about their interest and past experience with robots and programming. Materials: Slides, computer Demonstration Instructions: You should have a physical prototype (or at least video) to show students what they will be making. You should also have disassembled materials (at least of the cardboard) that you use to guide students through the instructions. Next Steps: Start handing out materials (one instructor can do this while the other presents) and begin instructing students on how to assemble the robot.

<u>Lesson—Part 2:</u> Objectives: Finish the physical components of the mini robot Materials: See above Demonstration Instructions: Show students how the finished robot will look and work. Provide handouts that describe each step, but walk through each step of the process (see below), assembling, at least the cardboard component, with the students. Activity Breakdown: Take the two cardboard boxes and tape one end of them shut. Cut off the "flaps"/tabs of one of your boxes (this will be the head) and set the tabs aside for later. Use a quarter or some other circular object to trace two circles for eyes on one of the cardboard boxes. This is the head of your robot. (Instrutor): Then, use the blade to cut out the two circles. Use a marker to draw other features, like whiskers, a nose, or whatever the students want their animal bot to look like. Use one of the "flaps" tabs that you set aside and put a piece of tape horizontally on it. Apply hot glue to the tab so that the tape surface is lined up with the holes you created on the head of the robot. Now use some marker to draw eyes for your robot. *Hardware* Take your two circular servo horns and two position servos and place the circular servo horn on the shaft of a position servo and screw it into place. Take the "X" servo horn (or any other one available) and screw it into place on your second position servo. Place the position servo with the circular servo horn on the center-top of your box. Trace around it. (Instructor): Using the blade, cut out a rectangular hole for the servo (tip: cut inside the line to ensure that the servo fits snuggly). Now you can insert your first

position servo. *Hardware* Next, you are going to calibrate your servo. To do this, turn the servo clockwise until it stops—we call this "position zero" and this will make the robot look all the way to the right. Now, turn the servo 90 degrees counterclockwise—this will make the robot look forward. Hot glue your second servo to the circular servo horn. (Instructor): Using the blade, cut a small rectangle below the servos to put the cord into. Cut one of the tabs in half to create two squares. Hot glue a square to the "X" servo horn and hot glue the second square to the first. Now you need to recalibrate your servo (turn it clockwise until it stops, then turn it 90 degrees). Glue the inside of the head to the second cardboard square. Your robot body is now assembled. Yay! Next Steps: Start handing out computers and ask students to open the link to take them to the web-editor. Students who don't want to program, or if they finish early can start designing the "animal" features of their robot.

Lesson—Part 3: Objectives: Program the robot to move its head along 2 axes. Materials: See above Demonstration Instructions: Version 1 is to allow students to explore the Hummingbird IDE and only show them the code for creating their bot and how to move it in one axes and then allow them to try and figure out how to do it for two axes. Version 2 is to go step by step through the code. Activity Breakdown: (TBD: still waiting to get permission for Birdbox IDE – demo (40-1:10 in this video)

9.2 Lesson plan 2

Extending work from Barnes et al. https://ieeexplore.ieee.org/document/8957388.

Lesson title: Robots as Performance: Drawing with Robots, on the Floor and in the Sky.

Background: Inspired by the Child-Robot Theater studies of the Mind Music Machine group, formerly out of Michigan Tech, we endeavor to introduce 5th grade students to problems in multirobot systems by inviting them into our Lab on Brown's campus and introducing them to a number of our technologies in the Automated Coordination of Teams (ACT) Lab.

Overview/Big ideas: The objective of this lesson plan is to further engage this cohort of students in the subjects of Robotics and Coordinated Mobile Robotics by connecting them with the remote control drone, painting drone, and CrazySwarm technologies at the ACT Lab.

Concepts: Path planning (using CrazySwarm), Intro to Robotics, STEM education, strengths of working in a pair or as a team

Design and Procedure: We will administer a survey about students' attitudes towards Robots/STEM prior to and after the in-lab robotics session. The activities will mainly consist of in-lab demonstrations and exercises with student groups.

CS/Robotics Teaching Strategies: Pair/group programming (for CrazySwarm web app), flying drone with remote control, watching demonstrations of robots' capabilities.

Equitable strategies: Low barrier to entry (start with easy assignments, assume little/no familiarity), Reducing imposter syndrome (build confidence early through successfully programming, all students can see themselves as "real" computer scientists/roboticists), Everyone has something to show off (if there are some students not interested in the hardware/software component, there are other fun parts to contribute to–like design and. . . ?)

What students will do: 20 min welcome/introduction and 120-min planned activities.

Alternative: 90-100-min planned activities and 20–30-min free play with robots.

What students will accomplish/learn: We aim to inspire excitement in students about STEM through an on-site visit to Brown University and through exposing them to robotics and the problems of multi-robot systems through the use of CrazySwarm and in-lab drones. In requiring teamwork, we ask that students consider the benefits of collaboration for creativity and to produce stronger results. Ideally, students' attitudes about STEM education would improve after the lab session, as gauged through the post-event student survey.

Lesson—Part 1: Objectives: Welcome and Tour of the Lab Materials: None - or a quick Google Slides? Introduction: Welcome to the lab, introduce the team, point out key elements of the lab and notable robots Demonstration Instructions: Activity breakdown: Icebreaker activity, everyone say their name and if they have ever met a robot or seen one on TV or in a movie

Lesson—Part 2: Objectives: Intro to Drone Flying Materials: Mini drone, remote control Introduction: Demonstrate flying drone in lab with remote control Demonstration Instructions: Use the remote control to fly a mini drone in the lab Activity breakdown: Students take turns flying drone after learning operation of controller Next Steps: Prepare for "Painting with Drone"

Lesson—Part 3: Objectives: Painting with Drone Materials: Drone, paint, canvas Introduction: Demo drone painting on a canvas Demonstration Instructions: Eric flies drone to paint on canvas. Students potentially add to the painting with their own figures - "collaborative painting with robots". Activity breakdown: Activity demonstrates art powers of robots. Next Steps: Move on to CrazySwarm web app demo.

Lesson—Part 4: Objectives: Intro to CrazySwarm Materials: CrazySwarm web app, in-lab computer (can be on laptops too if students have them) Introduction: Show coding in the CrazySwarm interface Demonstration Instructions: Demo a CrazySwarm animation on video or in real life Activity breakdown: Give coding assignment to group Next Steps: Group students together to try to use web app to fly CrazySwarm

Lesson—Part 5: Objectives: Flying the CrazySwarm Materials: CrazySwarm web app, in-lab computer (can be on laptops too if students have them) Introduction: Instruct groups to get started coding, with the goal of writing a program that makes a cool coordinated path amongst the CrazySwarm Demonstration Instructions: Activity breakdown: Next Steps: Get ready to demo the project

Lesson—Part 6: Objectives: Demo CrazySwarm projects Materials: CrazySwarm web app, in-lab computer (can be on laptops too if students have them) Introduction: Groups take turns showing off their programs Demonstration Instructions: Show CrazySwarm programs running on in-lab computer Activity breakdown: Next Steps: Get ready for reflection time

Lesson—Part 7: Objectives: Group Reflection Materials: Students and facilitators Introduction: Recap what we did today Demonstration Instructions: Group share through a set of reflection questions – what did we learn? How do we feel differently, if at all, about robots, than we did at the beginning of the class? Activity breakdown: Group share Next Steps: Break + get ready to go home