Unplugged Robotics to Increase K-12 Students' Engineering Interest and Attitudes

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***Abstract*—The impact of technology on workforce development and socioeconomic prosperity has made K-12 computing engineering and STEM in general a national educational priority. However, the integration of computing remains obstructed by resources and lack of professional development to support students' learning. Further challenging is students' STEM attitudes and interest do not matriculate with them into higher education. This issue is especially critical for traditionally underrepresented and underserved populations including females, racial/ethnic minority groups, and students of low-socioeconomic status (SES). To help mitigate these challenges, we developed an unplugged (computer-less) computing engineering and robotics lesson composed of two introductory computing concepts, sequencing and decision-making, using a small robot-arm and tangible programming blocks. Through students' sequencing of operations, debugging, and executing complex robotic behavior, we seek to determine if students' interest or attitudes change toward engineering. Nine one-hour introductory pilot lessons with 148 students, grades 6-10, at two public middle schools, and one summer camp were conducted. For 43% of students, this was their first time participating in an engineering lesson. We measured students' engineering interest and attitudes through a 15 question pre- and post-lesson survey and calculated aggregate factor scores for interest and attitudes. We found low-SES students' a priori interests and attitudes tend to be lower and more varied than those of their high-SES peers. These preliminary results suggest that the integration of introductory computing and robotics lessons in low-SES classrooms may help students reach similar levels of engineering interest and attitudes as their high-SES peers.**

Keywords—robotics; computational thinking; K-12

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I. Introduction

During the next decade, computing and robotics are key projected areas of U.S. economic development and labor force growth [1][2]. This growth places demands on society to equip its future workforce with the necessary knowledge and skill sets in computer science and engineering (CSE) and robotics. CSE and robotics education are subjects that have traditionally been exclusive to post-secondary institutions and widely inaccessible to K-12 students [3]. This is a critical drawback in the efforts toward diversification of STEM occupations as computing and robotics fields miss the opportunity to recruit women and traditionally underrepresented groups to the disciplines [4]. These trends are further perpetuated as students' STEM and engineering interest are often set by middle and high school grade-levels [5] and by the limited accessibility of computing and robotics instructional materials for public educators [6]. This combination of factors limit the opportunities that students have to interact with CSE and robotics prior to entering higher education or industry.

However, given the ubiquity of technology and the identified need to increase access to CSE and robotics, its integration in K-12 curriculum has become a U.S. priority in the last decade. Recent calls for reform from educational stakeholders such as the National Science Foundation are leading the conversation to correct the issue through the "CS for All" campaign [7]. But, this change is also dependent upon the research community. A need exists to establish research-based practices to teach CSE and robotics, to determine how students best learn computing and robotics, and to identify how students at different grade-levels and stages of cognitive development retain computing concepts [8]. As such, the purpose of this paper is to implement and examine the effectiveness of introductory computing and robotics concepts. We use a robot-arm and an unplugged (computer-less) programming platform, tangible user interfaces (TUIs), to construct curriculum that emphasizes both knowledge of programming and robotic manipulation. Specifically, we seek to understand how an integrated computing and robotics lesson for K-12 grades 6-10 effects student engineering interest and their conceptual understanding of fundamental computing abstraction. The lesson was designed to be approachable to novice educators and students of computing by eliminating dependence on outside technical expertise or costly resources. The content includes implementation of simple programming exercises, code debugging, and reasoning about robotic arm operation to generate explicitly sequenced commands for information sensing that accomplishes a known task. These skills are critical to an effective understanding of robotics. To make a contribution to the aforementioned research needs, we conducted nine one-hour pilot lessons with 148 middle and high school students in both traditional classroom settings and engineering summer camps.

II. Background

A. 5E Instructional Model

Our lesson framework is based on Bybees' 5Es instructional model, a research-based approach to lesson development involving engagement, exploration, explanation, extension, and evaluation of student learning [9]. This structure offers a tool for integrated instruction; an approach that connects laboratory experience and varied learning activities, including group investigations, discussion, and direct instruction [10]. Thus, students will interactively explore sequences, debugging, and sensing/decision-making concepts with hands-on resources by assembling code using unplugged programming blocks and a robot-arm to test their code.

B. Pedagogy

The aim of our lesson is to introduce three computing concepts to middle school and early high school students, sequencing, debugging, and sensing/decision-making [11]. We embedded our lesson with evidence-based pedagogical practices of active learning, teaming, and multiple opportunities for student talk. Active learning has been shown to increase student performance across STEM disciplines [12] and teaming shows evidence of increased student performance, motivation, and quality of solutions [13]. We integrated student talk using Think-Pair-Share, an activity that gives students time to develop an individual thought-process about a problem, 'think,' time to work with partners to improve and develop their solutions, 'pair,' and time to share and justify their ideas to their classmates, 'share' [14]. Further encouraging, Think-Pair-Share has shown to increase student engagement and conceptual understanding in CSE specifically [15][16] and to encourage elaboration of thought processes for difficult concepts [17]. Additionally, HRI education reinforces this lesson plan as recommended practices for teaching HRI content include high degrees of interaction between learners and robots [18].

C. Tangible User Interfaces

Tangible User Interfaces (TUIs) represent programming commands or actions through text and/or pictures in both computer-based and unplugged formats [19][20]. TUIs abstract the syntactical aspects of programming, facilitating a focus on learning fundamental computing concepts [21]. They are advantageous for educators in that they are often inexpensive, durable, permit collaboration, and are easily adaptable for different learning environments, rather than restricting learning to a computer monitor [22]. That said, the independence from electrical components means students' TUI programs will not directly control the robot-arm. This may cause a disconnection for students between program generation and robotic manipulation, which we attempt to address through the debugging and sensing exercises.

D. Debugging & Sensing/Decision-Making

Teaching debugging is a critical component in the early stages of computing as it is a necessary skill for effective programming. This concept is initially addressed during students' first iteration of code generation, and practiced throughout the remainder of the lesson. We ask students to take on the roles of "programmer" and "robot."; the "programmer" reads-aloud the assembled set of actions, while the "robot" executes the sequence of actions with their eyes closed to verify the code accomplishes the end goal, prior to testing with their robot-arm. This activity dually serves student's grasping of debugging and sensing/ decision-making concepts as errors are evident when the robot is not achieving its end goal, and when the "robot" cannot sense the block to know they can pick it up and move it. Further, this activity affirms the connection between programming and robotic control. Students' taking on the robot's perspective helps provide intuition for programming robotic operation in general, and addressing the aforementioned disconnection between unplugged program generation and robotic control.

III. Methods

To address the demonstrated need to integrate computing instruction in K-12 curriculum, we designed a lesson and study to investigate teaching middle and early high school students introductory CSE concepts through robotics. The intent being: to determine if students' interest in engineering and computing increased after participating in the lesson. Nine one-hour pilot lessons with 148 middle and high school students in both traditional classroom settings and engineering summer camps were conducted. The 148 participants were comprised of 82 students (55%) who participated in the lesson at the middle school they attend, and 66 students (45%) who participated in the lesson through a summer camp at a local university.

According to available 2013-2014 student demographic data, the student composition of the two middle schools consisted of 19% and 100% are students who receive free-and-reduced lunch; 29% and 81% are students who identify as racial/ ethnic minorities, 11% and 14% are students with individualized education plans (students eligible for special education services); and 4% and 30% are students who are English Language Learners, respectively. The free-and-reduced lunch designation means a students' family has a financial status that is at or below the national poverty line. Demographic information about the summer camp population was not available, but we assume the SES of the students' families to be middle to upper income brackets as a fee of several hundred dollars was required to participate.

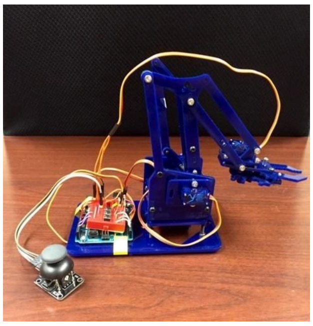
A. *Data Collection & Analysis*

Student interest and attitudes toward engineering were measured through a 15-question survey given before and after completing the CSE lesson. The survey instrument was developed using the Intersectional Non-Normative Identities in the Cultures of Engineering (InIce) instrument [23], which had been previously validated with over 4,000 first-year university engineering students. Survey items were adapted to meet the expected reading levels of participants. The survey asked students to mark their agreement of statements on a 7-point likert scale anchored between "Strongly Disagree" and "Strongly Agree". All statistical testing was done using R [10]. To develop factor scores for interest and attitudes, appropriate questions were aggregated. Socioeconomic status (SES) groups were determined according to each school's SES designation; a measure which places students' economic standing according to the financial standing of the overall student body where they attend [9]. That is, given the large income disparity between the two middle schools and the summer camp populations, we grouped the student population according to SES. The middle school with 100% of students that qualify for free-and-reduced lunch was designated low-SES, while the other middle school and the summer camp were designated high-SES.

Both the entire group, all 148 students, and the individual school groups, by school SES, were checked for normality and constant variance using a Q-Q plot and a residual plot. All data sets were determined to be non-normal. First, differences in pre- and post-interest and attitudes were checked across the combined population using a Wilcoxon Rank Sum Test (a non-parametric t-test). Differences were also checked along SES groups. Tests that were conclusive for group- differences were checked post-hoc with a boxplot. Significance for all tests was set at the α=0.05 level. The entirety of this study was approved by the local Institutional Review Board (IRB).

B. *Lesson Materials*

The robot-arm used for this lesson is a MeArm generated from an open-source MeArm CAD file [24]. A set of magnetic TUIs are generated by laser-cutting basswood, while a robot environment is created with three concentric half-circles on a sheet of butcher paper, a set of blocks are used as the pick-and-place task objects, and a white board is used for students to collaborate with the code development process.



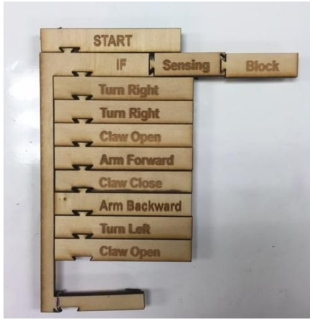


Figure 1 (left): The MeArm used to grasp and move blocks.
Figure 2 (right): The magnetic tangible user interface (TUI).

C. *5E Lesson Plan and Content*

Using Bybee's 5E Instructional Model, our lesson plan guided students through learning of sequences, debugging, and sensing/decision-making through students' construction of code that moves a block from an initial to a final position in the robot's environment.

Engage: The lesson begins by grouping students into pairs or trios and assigning each group a set of lesson materials (See Figure 1 & 2). Students are asked to retrieve their robotics background knowledge, as eliciting previous knowledge during new learning is a key element in increasing student's academic achievement [25]. Then, 2-3 students share their experiences with the class and the class discusses what robots are. We close out the 'engagement' portion of the lesson by formally defining 'robot' for students to make sense of their background knowledge. To introduce students to the logic of programming, we ask students to consider a relevant sequence of actions that they execute every day, brushing their teeth. We provide example code for teeth brushing that guides student thinking in the direction of how they will construct a complex program for a robot. Questions are then posed to students to reflect on sequencing, "Did the order of the steps matter" and "Can any steps be switched?" Driving this reflection was the Think-Pair-Share activity where students think, describe their thought processes with a partner, and then share their discussions with the class.

Explain/Explore: Next, we provided time for students to investigate, observe, formulate explanations, and clarify questions about their learning [10] through a series of three activities. *(1) Sequences to Actions*: First, students watch a video where a robot-arm sorts lemons and limes to demonstrate what they will accomplish with their MeArm. Then, we provide a small sequence of instructions similar to those that they will use in future exercises. We ask students to take on the roles of "programmer" and "robot." In these roles, students execute their provided programs with their own arms, mimicking the same actions their robots will complete. Finally, students verify the code with their MeArm. This lesson activity offers students a means of gaining intuition of robotic control. *(2) Designing Sequences:* To extend the depth of this exploration, students execute a second sequence, this time self-constructed, using their magnetic TUIs. The instructor simply provides the initial and goal positions for a block. The students' goal is to program the robot-arm to go to the initial block position, grab the block, and move and place the block in the goal position. As with the first program, students will take on the roles of "programmer" and "robot" to debug their program, prior to executing it with the MeArm. *(3) Redesigning & Debugging Code:* For the final programming activity, students are again provided with initial and final block positions and a program sequence, but this sequence will contain an error. Multiple solutions exist for students to fix the bug. Debugging a sequence provides students time to reflect and brainstorm possible solutions to an error and to identify the best solution based on their discussion. This process is a key component of computational learning and the engineering design process [26]. Lastly, we ask students to exchange their code with a group, affording each group with an opportunity to verify another team's code and evaluate their solution. After, students are asked to reflect on how missing one step can significantly deviate the end goal and to consider examples of how this happens in their own lives (e.g., you can't put on your shoes before your socks).

Extend & Evaluate: Each group is given a worksheet with two blank mats for an initial and a final block position. The groups choose what the two positions are, draw them on their worksheet, and trade worksheets with a neighboring group. The groups are then asked to produce a sequence of instructions that accomplishes moving a block from the provided initial and final positions. Finally, an assessment with problem-solving questions for students to apply sequencing and debugging skills was created. Conceptual questions are also posed about sequences not explicitly related to computer science.

IV. Results

A population of n=146 students grades 6-10 participated in our CS and robotics lesson and completed pre- and post-lesson surveys about their interest and attitudes toward engineering. 43% of students reported that this was their first experience with an engineering lesson. Students were sorted according to two income groups, low-SES, n=94, and high-SES, n=52. The initial Wilcoxon Rank Sum Test for differences between the entire groups pre- and post-interest (W=9806.5, p=0.22) and attitude (W=9464.5, p=0.10) scores were insignificant, suggesting no difference in interest and attitudes before and after the lesson delivery. Follow-up tests for differences between SES groups also showed no significant differences exist between students total change in pre- and post-interest (W=2044.5, p=0.08) and attitude (W=2247.5, p=0.42) scores. Although these tests were insignificant for differences across SES groups, we also tested for differences between pre-interest scores, post-interest scores, pre-attitude scores, and post-attitude scores, by SES group. Differences were found between pre-interest scores by SES (W = 3381, p <0.001), post-interest scores by SES (W = 3042, p = 0.01), pre-attitudes scores by SES (W = 3530, p <0.001), and post-attitudes scores by SES (W = 3302.5, p <0.001) Illustrated in Figures 3 and 4, these differences highlight that low-SES students had lower pre- and post-interest, and lower pre- and post-attitudes than their high-SES peers.

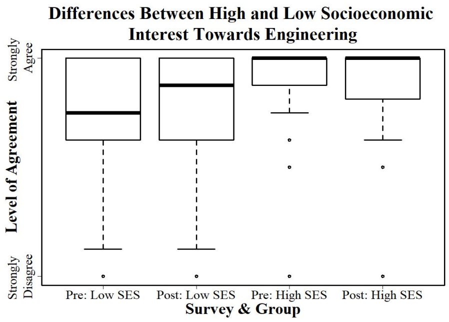


Figure 3. Differences in interest scores by SES group.

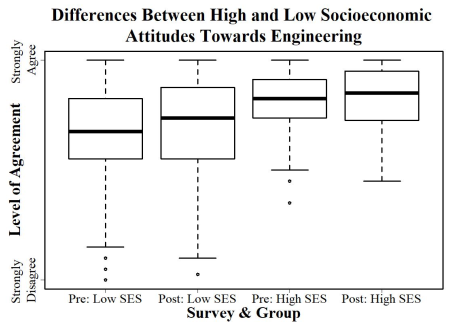


Figure 4. Differences in attitude scores by SES group.

V. Conclusion

As a demonstrated need exists to increase understanding of students' STEM interest and attitudes, including how to design instruction that positively impacts those attitudes. Data analysis of our middle school populations by income-levels revealed an increase in interest toward engineering for low-SES students. This suggests that students of low-SES and/or are racial/ethnic minority populations have more to gain from access to engineering lessons similar to ours than students who are not. Further, middle school is an integral time for students to be introduced to these topics as it is the time period when a foundation is laid for post-secondary STEM success [27]. Moreover, interventions that target student populations with less access to computing and robotics may help shift the decline in students' early-on STEM interest as they matriculate through K-12 grades [6].

VI. Future Works

Gaining a more comprehensive understanding on the findings from this work in progress may be achieved by focusing on particular populations. 45% of our sample population included students who participated in this lesson through a high-cost summer camp and thus were self-selected for interest in engineering. Evaluating and comparing schools with large student populations of low-SES and high-SES and/or racial/ethnic minority students may reveal how and why these populations' initial interest and attitudes in engineering shift. Additionally, doing research with a baseline population of students who have not previously participated in engineering lessons may provide an upper bound on possible gains for engineering interest and attitudes. Future work should also involve participants that are more reflective of K-12 students populations to reduce the ceiling effect for interest and attitudes toward engineering. In general, increasing the size and diversity of sample student populations should be considered for works that extend these findings. Lastly, because our survey instrument was specific to engineering, next steps should involve development of robotics and computing measures of interest and attitudes that reflect culturally relevant aspects of computing education.

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