Student Outcomes from the Evaluation of a Transdisciplinary Middle School Robotics Program

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***Abstract*—Robotics activities allow students to gain confidence in their abilities to use technology creatively, express themselves, and solve problems of interest. However, many traditional robotics elective programs suffer from self-selection and reach only a subset of students. Arts & Bots is a middle school robotics program which integrates robotics into non-technology classes to engage a more diverse population of students. In this paper, we present the collected student outcomes from our program evaluation study which ran from 2013 until 2017. During this time, Arts & Bots was implemented by 24 teachers in 66 classes, reaching 727 middle school students. Program evaluation data included pre- and post-surveys, daily reflection sheets, project presentation videos, and classroom observations. Between pre- and post-tests, we recorded better student understanding of what engineering careers entail, and found that female students caught up to their male peers in their understanding. Our analysis also shows pre/post improvement in student technical knowledge. Quantitative survey results are complemented by our coding and analysis of qualitative student short answers. We found that female students were significantly more likely than male peers to mention increases in confidence on the post-survey. This paper concludes with a discussion of trends in the evaluation results.**

Keywords—educational robotics, interdisciplinary education; transdisciplinary education; technology fluency; K-12 engineering

I. Introduction

Educational robotics programs, like Arts & Bots, are becoming increasingly popular and widespread as a means of engaging K-12 students both in-school and out-of-school. Popular educational robotics initiatives such as US FIRST [1] and VEX [2] emphasize task completion goals in high intensity, competitive environments. Unfortunately, these types of programs can be intimidating to students who lack existing experience with robotics. These technology programs are frequently motivated by technology and engineering challenges which some students do not find engaging. Further, most robotics programs are offered as electives which can lead to student self-selection and as extracurriculars which can prevent participation of students whose families lack the resources to support participation. In contrast, our robotics program, Arts & Bots, emphasizes creativity and expression, aiming to include students unmotivated by these types of programs [3] [4] [5]. By situating Arts & Bots in required non-technical classes, such as English or History, we both eliminate student self-selection and contextualize the technology task within a non-technical domain. Our focus in developing Arts & Bots was initially to engage middle school girls with robotics but has expanded to include students of both genders.

II. Arts & Bots Overview and Prior Work

Arts & Bots was first developed at Carnegie Mellon University in 2006 in response to dropping enrollment by women into engineering and computing degree programs [3]. Since then, we have supported its use in K-12 classrooms across the United States as well as internationally. Through integration with core coursework, rather than implementation as an after school club or elective technology course, we assert that Arts & Bots has the potential to impact and enhance STEM education for all students and not just those with recognized existing affinities towards STEM activities. We hypothesize that Arts & Bots will help students self-identify as individuals with the creative problem-solving capabilities needed to become future creators and innovators in STEM disciplines, as discussed in our prior work [6], helping to fill the needs of the future job markets not met by the current educational system [7] [8].

Arts & Bots is an educational robotics program which provides students with hands-on experience with robotics technologies, engineering design, and computational thinking while integrating with core disciplinary content in areas such as English Language Arts, Science, and Social Studies. The primary goal of Arts & Bots is to increase students' technological fluency while smoothly integrating technology into classrooms across disciplines. We define technological fluency as the skills, knowledge, and attitudes required to develop creative technology solutions for one's own purpose. The Arts & Bots program combines (1) craft materials, (2) a flexible hardware kit, (3) a custom visual programming environment [9], (4) teacher professional development, and (5) adaptable curriculum to empower students to create robotic sculptures aligned with class content [10]. Craft materials promote a gender-neutral and intrinsically creative design process, key features of Arts & Bots. The Arts & Bots hardware kit is designed to foster the creation of engaging,

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Fig. 1. Sample Arts & Bots projects. From top left: student programming a scene from Romeo & Juliet; Stonehenge; student learning about complementary muscle pairs while constructing a knee joint.

narrative-based robots. Outputs (DC motors, hobby servos, tri-color LEDs, single color LEDs, and vibration motors) encourage expression, and sensors (temperature, light, sound level, IR distance, and a potentiometer) support interaction with the robot [11].

In our earlier papers, we describe how Arts & Bots has been integrated into many subject areas [4] [5]. Fig. 1 shows a few examples of student work during Arts & Bots projects. English Language Arts teachers have used Arts & Bots to help students deepen their comprehension of poetry or explore symbolism in Shakespeare. Health and Physical Education teachers have used Arts & Bots projects to help students explore the relationships between complementary muscle pairs within our limbs, and Social Studies teachers have used Arts & Bots projects as a way for students to explore ancient structures and Greek gods. Example curricula exist in science, art, and even foreign language and choir classes [12]. While each of these projects focuses on the disciplinary goals of the integrated class, students also receive an introduction to basic robotics components and hands-on practice with the engineering design process as they work in pairs or teams to design and build their robot [6]. They receive an introduction to programming concepts and computational thinking as they program their robotic creations to move, react to sensors, light up, and play sounds [10]. Our prior pilot research on Arts & Bots classroom projects has shown that students exhibit gains in learning about robotics, improvement of confidence with technology, shifts in their stereotypes about how technology can be used and who uses technology, and gains in complementary non-technical skills such as teamwork [13]. In this paper, we build upon this prior work to present student outcomes data from our larger Arts & Bots study which took place between 2013 and 2017.

III. Related Works

These programs vary widely in their intended instructional goals, their complexity level, and the design of the systems used. Benitti presents a literature review of 70 educational robotics studies and illustrates the potential of robotics for education while highlighting the need for more structured research [14]. Educational robotics systems frequently come two discrete formats. Some robotics programs feature pre-constructed robots, as seen in the Finch robot [15] and the Parallax Scribbler robot [16], which allow students to spend all of their work time focused on the computation aspects of robotics. The other type of robotics programs provide kits of curated and custom hardware components which allow students to construct their own robots, allowing them to practice mechanical design and prototyping, but at the cost of time spent away from computing concepts. Arts & Bots is based around one of the latter, kit-based, robotics platforms and thus the most similar programs to Arts & Bots are other kit-based programs, namely: LEGO MINDSTORMS, PicoCricket, and Artbotics.

LEGO MINDSTORMS is an extremely popular and widespread educational robotics platform. Using LEGO elements in combination with motors and sensors, students are able to build and program their own functioning robot. The system is commonly used as part of competitions such as FIRST LEGO League [17]. However, Bers [18] describes how MINDSTORMS can be used to engage young students in engineering through storytelling in an approach similar to the expressive and creativity-oriented approach used by Arts & Bots. The PicoCricket System combines LEGO bricks and craft materials with control of light, sound, music, and motion with the goal of engaging a more diverse student population with robotics. Rusk et. al [19] describe their approach of combining engineering and art for use in storytelling and using exhibitions rather than competitions, to engage diverse learners. Artbotics is a course targeted at high school and undergraduate students in which students design interactive museum art projects [20]. Artbotics initially used the Super Cricket microcontroller and later the LEGO MINDSTORMS system to control the pieces' sensors, motors, and lights. Similar to the way that Arts & Bots integrates robotics into disciplinary classes, Kim et. al. explore the balance between Art and Computer Science in undergraduate coursework using the Artbotics [20].

IV. Methods

Between 2014 and 2017, 24 teachers from two districts, a suburban school district in Pennsylvania and a rural school district in West Virginia, completed Arts & Bots projects in 66 classes. Teachers participating in the partnership received approximately two days of professional development each year that they participated in the project. We assigned each class

Below is a list of actions. Check off whether each action is an input of information, the output of information, or the processing of information. (Multiple choice: Input/Output/Processing)

1. A beep from your computer
2. Pressing a button on your phone
3. A printout from your printer
4. Thinking about which soda you want from a machine
5. A picture on your computer monitor
6. Talking into a cell phone
7. A calculator adding a sum
8. The movement of a remote controlled car
9. The ringing of your alarm clock
10. Your digestion of breakfast

Fig. 2. The Systems Engineering scale asks students to identify whether a system action is an input, output, or processing action.

project an implementation code. If a teacher taught multiple projects on the same class topic simultaneously, they were clustered into one implementation code. For example, a teacher who completed Arts & Bots in three 7th grade, English Language Arts classes during first, fourth, and sixth period within the same time frame was counted as a single implementation. There were 43 separate project implementations during the research period. These projects involved 728 unique students. Some students participated in more than one implementation, such that there were 1265 separate student experiences. Of those students, 302 students were from the suburban district, and 425 students were from the rural district.

Total implementation time varied between implementations and teachers but the students are frequently given approximately ten class periods (45 minutes per class), the first and last of which are used to complete research surveys. The remaining eight are used to research, design, build, and present the entire project. Typically, three class periods are used to research and design. Approximately four class periods are dedicated to building, programming, and preparation for presentation. Students then present their project on the final day of the implementation [5].

Students were surveyed before and after the project, and these surveys form the focus of the evaluation presented here. The complete pre and post surveys are shown in [21]. Project research instruments cover three subjects: student experiences during Arts & Bots; student technical knowledge; and student attitudes towards technology.

The number of students in the data samples below varies slightly since our survey tools undergo regular refinement and modification of wording. Consequently, items that were introduced more recently may have fewer responses. The analysis in this paper excluded participants who did not meet the following two conditions: 1) were enrolled in a middle school class, and 2) did not complete both a pre and a post survey. Of the 462 included participants who met this criteria, 455 indicated their gender on post surveys; 226 (48.9%) were male and 229 (49.6%) were female.

A. *Short Answer Questions*

We reviewed student short answer responses as a way to gather insight into student experiences. In total, we coded responses from four questions: "Are you excited to do this project? Why or why not?", "Did you enjoy this project? Why or why not?", "How did this experience change how you think about technology?", and "What was the best thing you learned?" The coding scheme used to code the open-ended responses was previously tested on a subset of student responses (N=275). The interrater reliability was found to be Cohen's Kappa = 0.762 ($p<0.001$) [8]. In total, 58 cross-question codes could be assigned across questions, with a small number question-specific codes available for assignment. No limit was provided regarding the number of responses allowed to be assigned to each response. When there was a disagreement on code assignment, the raters discussed and chose the specific codes to be assigned. The complete coding protocol is provided in [21].

B. *Systems Engineering Scale*

The technical knowledge section of the student survey contains a set of questions designed to measure a student's understanding of the systems engineering concepts of inputs, outputs, and processing of information. These concepts are widely applicable to systems ranging from robotics to biological systems to ecosystems. The systems engineering questions are adapted from Sullivan (2008) and include ten items describing actions of devices and subsystems [22]. The students were prompted to indicate whether each action is an "Input," "Output," or "Processing" action of the system, these items are listed in Fig. 2.

C. *Robotics Activites Attitudes Scale*

We developed a scale of Likert-type items to assess student attitudes with respect to technology, which we refer to as Robotics Activities Attitudes Scale (RAAS) [23]. This scale is designed to measure the effectiveness of creative robotics programs in modifying middle school student attitudes towards technology and, more specifically, robotics. The final attitudes scale had questions that were distributed among dimensions as follows: confidence (10 items), learning potential (10 items), personal technology identity (10 items), personal robotics identity (10 items), and curiosity (6 items). Cross et al. (2016) lists all of the items that are in each dimension used in the 2010 version of the RAAS. The items were constructed as 46 Likert-like scale items where students stated their agreement with various statements on scale consisting of "NO!", "no," "neither yes or no," "yes," and "YES!" which we scored with a -2 to 2 scoring where -2 was "NO!" and 2 was "YES!" These scores were summed to provide composite sub-scale scores. Thus for each scale dimension, the range of possible scores was: confidence (-20 to 20), learning potential (-20 to 20), personal technology identity (-20 to 20), personal robotics identity (-20 to 20), and curiosity (-12 to 12). In each of these ranges, the lowest possible score indicates all statements were disagreed with strongly ("NO!"), the high score indicates strong agreement ("YES!), and a score of zero is equal to all neutral responses ("Neither yes or no").

Are these things that an engineer would do for his or her job? (yes/no)

1. Develop better bubble gum
2. Install cable television
3. Nail beams together for new houses
4. Come up with ways to keep soup hot for a picnic*
5. Develop smaller cell phones
6. Drive motor boats
7. Design tools for surgery*
8. Design ways to clean polluted air
9. Drive garbage trucks
10. Figure out ways to explore the ocean
11. Install wiring
12. Put shelves together in a store
13. Pour cement for new roads
14. Figure out how tall you can safely build towers*

Fig, 3. The Engineering Career Perceptions scale asks students to identify tasks engineers might do in their jobs. Individual items marked with * showed significant improvement between pre- and post-surveys.

D. Engineering Career Perceptions

Finally, we include in the student survey a scale related to student perceptions of engineering careers. The scale was developed by the Engineering is Elementary team for measuring elementary school student' knowledge of the work of engineers, as well as naive conceptions about engineering [24]. Through the recommendation of the scale authors and review of their raw pilot data, we refined their 37-item scale for our age group by creating a modified scale from the 14 most difficult items from their testing. The items are provided as simple yes or no questions, which are scored based on average responses collected from professional engineers. The resulting 14-item scale is in Fig. 3.

V. Analysis & Discussion

We present analysis and discussion of student outcomes grouped around four themes: technical knowledge and skills, student dispositions, teamwork, and gender comparisons.

A. Student Technical Knowledge and Skills

One of the primary goals of Arts & Bots was to enhance students' technical knowledge and skills. Knowledge and skills are key components of technological fluency as described above. The student attitudes components of technological fluency are discussed later in this section. Our evaluation of student technical knowledge and skills focus on generalizable concepts that are not specific to the Arts & Bots hardware or software platforms, namely systems knowledge and student perceptions of engineering careers. We highlight these areas of transferable knowledge and skills as they are valuable beyond a student's Arts & Bots project.

1) Systems Engineering

Students completed the systems engineering 10-item scale, described above, during their pre and post-surveys. The total scores did not follow a normal distribution (Fig. 2), which we accounted for in our analysis with a Wilcoxon-signed ranks test. The bimodal distribution of scores, which is particularly apparent in the post scores, is an interesting feature of our data that we are continuing to explore the cause of. Some students,

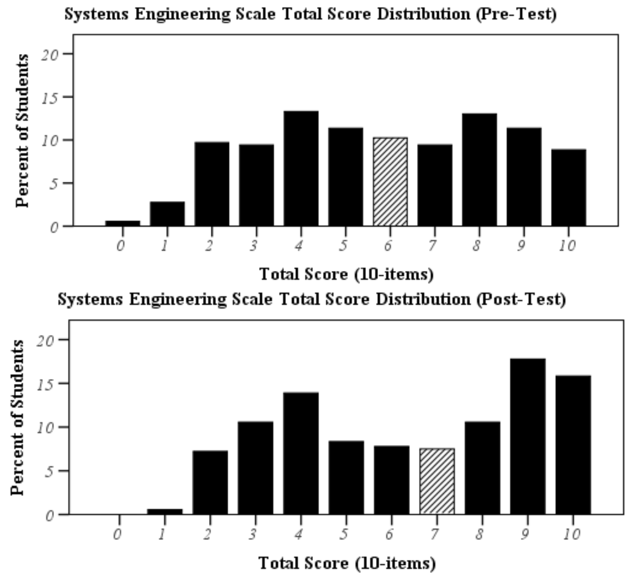

Fig. 4. Distributions of total score for the 10-item Systems Engineering scale on student pre and post-survey for students' first Arts & Bots experience. Students scored significantly higher on the post test. Median scores are highlighted.

perhaps due to survey fatigue, respond to the entire scale by selecting a single response type, either "input," "output," or "processing, " (Pre: 3.4%, N=794; Post: 6.5%, N=782). We removed these atypical responses from the following analysis.

A Wilcoxon Signed-ranks test indicated that, during their first Arts & Bots experience, students scored higher on the systems engineering items during the post test (Median = 7) than on the pre-test (Median = 6), Z = -5.735, p < .000, r =.303, N =357.

When the separate subsets of Systems Engineering Items were divided by type (5 output items, 3 processing items, and 2 input items), we saw that students demonstrated a significant pre-post increase on the five output items (Z=-5.816, p<.000, N = 358) but the difference was not found to be significant for input and processing items. The difference in significance may be attributed to the larger number of scale items devoted to outputs or may partly be attributed to the smaller amount of class time devoted to discussing sensor components and processing. Interestingly students demonstrate a significant improvement in their ability to correctly identify these system features after participating in Arts & Bots even though systems models are not an explicit topic of instruction.

2) Engineering Career Perceptions

Students complete the *Engineering Career Perceptions* scale, as described above, as part of their pre and post survey. During our exploration of the data, we found an atypical number students were scoring 7 out of 14 items, far more than would be expected considering the normal distribution of the majority of scores. We determined that this could be attributed to students, perhaps out of frustration or survey fatigue, selecting exclusively "Yes" or "No" responses for the entirety of this scale. This type of response accounted for 4.9% of student pre-survey responses (N=803) and 7.0% of student post-survey responses (N=790). Students with these response patterns were omitted from the following analysis.

During students' first experiences, we saw a significant increase in the number of items that students got correct on this scale between their pre (M = 8.1068, SD = 2.644) and post surveys (M = 8.564, SD = 2.753) ($t(364) = 3.780$, $p < .000$, $d = 0.169$). This difference was also seen during students' second Arts & Bots experiences between their pre-survey (M=8.818, SD = 2.804) and their post-survey (M=9.214, SD = 2.883) responses ($t(153) = 2.448$, $p < .000$, $d = 0.139$).

The most notable improvements were seen on design-oriented items where students would initially classify the task as not engineering but on the post-survey would classify it as engineering. Our McNemar's test determined that there was a statistically significant difference in the proportion of students who agreed that engineers would "come up with ways to keep soup hot for a picnic," between the pre- and post- survey (p=.000, N=418). There was also a statistically significant difference in the proportion of students who agreed that engineers would "design tools for surgery," (p=.023, N=418). Additionally, we saw a larger number of students agreeing that an engineer would "figure out how tall you can safely build towers," on the post-survey, however, this difference was not significant (p=.051, N=417).

It is again interesting to note that students' perceptions and understanding of engineering careers improved despite minimal to no formalized instruction on the part of teachers around engineering careers and the tasks that they involve.

3) *Self-reported Knowledge Gains*

In addition to technical learning seen on the multiple choice item scales, we also saw students self-reporting technical knowledge and skill gains on the short-answer questions. In the three post-survey open-ended response questions that were coded, a large number of students responses were assigned the *Technical Learning* code, meaning that students were self-reporting learning something technical.

Following the project 63.2% of the answers (N=342) to the question "What was the best thing you learned?" were assigned the *Technical Learning* code. These answers mentioned the acquisition of skill or an understanding of how technology worked. For instance, a seventh grade, male, social studies student said that he learned "what wires go where." Another seventh grade, male, social studies student described his new programming knowledge, saying the best thing he learned was, "How to program the parts so they all run in a cycle the way we want." 25.4% of all responses (N=342) to the question, "How did this experience change how you think about technology?" described technical learning. Students self-reported this knowledge acquisition, for example, explaining, "I better understand how technology works now and especially understand the time, patience, and commitment necessary to program robots" (seventh grade, female, health). Even when coding the question, "Did you enjoy this project?" 12.6% of all responses (N=429) were identified as describing technical learning. For example, a typical response for the code is, "yes because I didn't know how to program but now I do" (seventh grade, male, social studies).

Together, the combination of student self-reported learning gains and improvements seen on the multiple choice scales of both the pre and post test indicate that the Arts & Bots program is achieving our goal of increasing student technical knowledge and skills as part of technological fluency.

B. *Contradictory Student Disposition Data*

When analyzing the student sub-scores on the RAAS attitudes scales, discussed above, we found that our results did not align with our research hypotheses. We expected that through their participation in the Arts & Bots projects, students would have increasingly positive attitudes towards robotics and technology, with regard to *Confidence*, *Curiosity*, *Learning Potential*, *Robotics Identity*, and *Technology Identity*. However, our RAAS data suggests the opposite outcome. In all but one of the sub-scores, we see significant decreases in student attitude scores between pre and post surveys: *Curiosity* (N=423, Mpre=3.8, Mpost=1.6, p<.000), *Learning Potential* (N=205, Mpre=9.5, Mpost=5.1, p<.000), *Robotics Identity* (N=422, Mpre=-.4, Mpost=-.14, p<.000), and *Technology Identity* (N=203, Mpre=5.6, Mpost=3.0, p<.000). For *Confidence*, the difference was not significant.

The reason or mechanism for these decreases remains an open question in our evaluation. It is especially interesting since this information is in opposition to findings from our qualitative data such as interviews, observations, and short-answer questions. One natural assumption would be to conclude that the reduction in how much students identify with robotics and technology was the result of students have negative project experiences. However, we see that the opposite is true in our short answer coding. When students following their first Arts & Bots experience were asked: "Did you enjoy this project?" 79.3% answered in agreement (N=420), in comparison with 12.6% who answered in disagreement and 7.1% who had mixed positive and negative responses. This indicates that the large majority of students enjoyed the Arts & Bots experience.

Another possible mechanism could be the existence of a novelty or anticipation effect before the start of the Arts & Bots project. Teachers frequently announce the start of the Art & Bots project immediate before students complete their pre-surveys, which could result in students' attitudes being artificially inflated while they complete the pre-survey due to excitement regarding the upcoming robotics project. This hypothetical mechanism is in keeping with some analysis of our short answer questions. For example, we noted several changes between first and second experiences with Arts & Bots when looking at the pre-survey question "Are you excited to do this project?" that may help explain the attitudes shifts seen in the quantitative data. On first experience (N=216), 18.5% of students reported *Novelty* as something they were excited about, however, on entering the second experience (N=179) only 9.5% of students were excited about *Novelty*. A similar drop in excitement can be seen for *Technical Learning*, going from 13.0% upon the first experience to 6.1% upon entering the second experience. We interpret these two statistics together to show that students are excited about the unknown before their first Arts & Bots project, but after completing a project (i.e. at the time of the second experience pre-survey), some of that novelty has worn off. Overall students are still looking forward to the project at the start of the second experience with a similar level of the code *Fun* expected: first experience 34.7%, second experience 34.6%. Slightly more students in the second experience say they don't like technology (3.4% vs. 2.3%). Interestingly the number of students who said they were excited because they enjoy building increased from 4.6% to 11.7% between first and second experience. While 6.1% of second experience students say they had a prior negative Arts & Bots experience, 17.9% reference a prior positive Arts & Bots experience as in "Yes, because in the past I have done other arts and bots projects and was very excited and interesting," (seventh grade, male, social studies). These survey results could be interpreted to mean that at the start of the second project, students have more first-hand experience on which to base their expectations.

Another factor for consideration is that because we are engaging all students in required classes, without the self-selection usually present in elective technology classes and extracurricular activities, it is expected that some students will not find engineering and technology coursework to their liking.

C. Teamwork

Arts & Bots is an open-ended project that is sufficiently complex such that a single student cannot be expected to complete the project on their own within the given time. As mentioned above, students worked in teams to complete their robot projects. Teachers generally assigned students in teams of 3, but sometimes teams were smaller or larger when classes could not be evenly divided. Most teachers assigned teams through random assignment or consideration of student personalities and dispositions. A smaller number of teachers let students choose teams. Student mentions of *Teamwork* especially stood out during our coding and analysis of the short answer questions from students.

In the pre-surveys, we saw that a small number of students were excited to participate in Arts & Bots projects because of the opportunity to work on teams. When answering the pre-survey question, "Are you excited to do this project?" only 3.3% of students (N=428) mentioned teamwork. When talking about teamwork, students frequently mentioned that they were excited to do the project because they would have the opportunity to work with their friends. Responses such as "Yes because it gives me time with my friends," (sixth grade, male, science) and "Yass, Im very excited because i get to work with my friends on the arts an bots [sic]," (eighth grade, female, science) were typical. However, since teachers most frequently assigned teams, it is unlikely that teams were formed exclusively of friend groups.

In the post surveys, we saw a larger percentage of students discussing teamwork in the short answer questions as well as changes in how students described teamwork in those responses. When answering the question, "Did you enjoy this project?" 17.2% of students cited teamwork as one of the reasons that they enjoyed the project (N=429). For instance, an eighth grade, female student described her teamwork experience in her English Language Arts project by answering, "Yes I did because my group pulled all of their weight."

Additionally, many students mentioned teamwork when responding to the post-survey question "What was the best thing that you learned?" (19.0%, N=342). While some students say they learned teamwork without being specific, many describe specific skills they learned such as patience. For example, "how to keep patience with your group and help them learn more," (seventh grade, male, social studies), and "I learned to be patient with my partners because I might not always be with a classmate that I enjoy. I now know that it is not worth arguing with someone over a placement or a small light flash. It is more efficient to work together and create something amazing," (eighth grade, female, English Language Arts). Other students describe communication skills as in [I learned] "Team work and to talk not yell and take your time," (eighth grade, female, English Language Arts). In response to the question "What was the best thing that you learned?" some students mentioned the value of teamwork, noting that working together is essential and that everyone contributes something of value. For example, a seventh grade, female, social studies student said, "The best thing I learned during this project was really working as a group because nobody would've been able to complete this project without working together."

Unfortunately, not all students have positive team experiences in open-ended projects like Arts & Bots. It is widely recognized that it can be challenging for student teams to work together effectively and that failures in teamwork can negatively impact student experiences [25]. Team problems can arise from many sources, such as an individual student not contributing at their full potential or a random team assignment which does not produce well-balanced teams [26]. Some students noted teamwork as the reason that they did not enjoy the project (2.8%, N=429) when answering "Did you enjoy this project?" The problems described by students align well with others' descriptions of student team failure [26]. For instance, some teams' challenges were caused by the actions of individual students; students did not contribute to their teams, leaving their partners feeling frustrated. Students describe that frustration explaining, "No, I didn't enjoy this project because I had very inexperienced partners who were unwilling to help. In the end, I have completed the project by myself," (seventh grade, female, social studies). At other times, there seemed to be an imbalance within the group dynamic, with individual students taking complete control of their teams. Their partners did not have the opportunity to play a role in decision making or robot creation. As a result, they did not enjoy the project saying, "No because my partner wouldn't let me do anything and then yelled at me because SHE wouldn't let me work," (seventh grade, female, social studies). Yet other teams suffered from poor communication skills and lack of teamwork experience, for example, "not really my group and I did not work and communicate well," (seventh grade, female, social studies).

Teamwork is recognized widely as both a successful tool in education and a critical skill for students as they enter their future careers [26]. As such, it is important that students are provided with opportunities to practice teamwork skills, such as communication and project management. Open-ended team projects, like Arts & Bots, have the potential to provide students with those opportunities. We hypothesize that many Arts & Bots students are developing these skills from their positive teamwork-oriented responses to both prompts, "Did you enjoy this project?" and "What was the best thing that you learned?" A student saying that they learned that "if your group isn't the group you want deal with it and find another way to work around it," (seventh grade, female, social studies) demonstrates a growing disposition towards compromising and problem-solving within a team. However, the negative teamwork-oriented responses also show us that these experiences are not consistent across all students, classes, and teachers. While we have seen some teachers develop handouts to support teamwork, such as role assignment sheets, the current Arts & Bots professional development program [10] does not provide any training or materials to help teachers mediate or scaffold teamwork for their students. Due to the importance of teamwork in the student Arts & Bots experience, as reflected by our analysis, we are looking towards integrating teamwork-specific training in future teacher preparation.

D. Differences and Similarities between Genders

Finally, we present a detailed analysis of the differences and similarities between the outcomes for male and female students. Because a primary goal of Arts & Bots is to be inclusive of those underrepresented in other robotics and engineering activities, we felt it was important to analyze our data by gender, as women are traditionally an underrepresented group. Upon review of our data, we found four significant differences when analyzing student open-ended responses, and one significant difference in our quantitative analysis. Though overall, males and females are self-reporting similar experiences, indicating that Arts & Bots is achieving its goal of appealing to and including both genders.

When asked "Are you excited to do this project?" *Fun* and *Novelty* are the most common and second most common code assigned for both genders. *Technical Learning* and *Enjoy Building* feature in the top five for both. The significant gender difference between responses to the "Are you excited" question involved responses coded as *Vague Learning*, that is responses that anticipate learning without specifying the learning topic. For example, one female, sixth-grade student said before beginning her implementation in her technology class, "yes im very excited because I think it is very cool and exciting to learn new things." We found that 4.9% of males (N=206) and 13% of females (N=215) gave responses that fit this category. This result is significant at $p < .05$, χ^2 (2, N=421)=8.5493, p=0.003.

When reviewing answers to "Did you enjoy this project?" (Table I) we found a significant difference between males and females reporting enjoyment of the *Multidisciplinary or Creative* aspects of the project after their first experience, χ^2 (2, N=422)=12.609, p<0.000. This response from an eighth grade, female, English Language Arts student is representative of this code, "yes I did because I love making scenes come to life." On the post survey, 11.2% of female students reported this code while only 2.4% of male students reported it. Both males and females, however, responded that they enjoyed the project because it was Fun (males 33.8%, females 31.6%), a *Positive Teamwork* experience (males 15.5%, females 19.5%), or provided *Technical Learning* (males 11.1%, females 14.4%).

For "How did this experience change how you think about technology?" male and female responses followed very similar patterns. The top seven most common positive response categories were the same and ranked in the same order as shown in Table I. When coding answers to this question, we did not find significant differences between male and female response rates of raw categories. However, when looking at the macro-categories of codes, within the macro-category which combines *Increased Confidence* (internal decrease in difficulty) and *Easy* (external decrease in difficulty), we see a significant difference, χ^2(2, N = 335) = 3.8346, p = 0.05. Responses assigned to *Easy* focused on technology being easier than expected. For example, a seventh grade, female, social studies student said, "It showed me that technology isnt as hard as i thought it would be." Responses coded as *Increased Confidence* referred to the student's assessment of their own skill increasing. For example, a seventh grade, female, English student said, "It made me feel more comfortable now using technology because I feel now I know what im doing.". We found 8.1% of males (N = 161), 14.8% of females (N = 174) gave responses in this macro-category.

When reviewing responses for "What was the best thing you learned?", both males and females only had two code categories with above 5% of the responses per category: *Technical Learning* (males 63.4%, females 62.6%) and *Teamwork* (18.0% males, 20.1% females). We can see that despite differences in confidence, reported learning by gender is quite similar.

Finally, when grouped into positive, negative, or mixed/neutral responses, there was only one significant difference between genders on the open-ended questions as a whole. Males had significantly more negative responses (7.6%, N=158) than females (2.4%, N=169) to the question "What was the best thing you learned?", χ^2(2, N=327)=4.7962, p=0.028.

While overall gender responses to open-ended questions are quite similar, with the few exceptions noted above, we found a significant improvement in the performance between the pre and post-survey *Engineering Career Perceptions* section exploring what an engineer does. During their first Arts & Bots experiences, we saw that females had a significant increase in their scores on this section between their pre (M=7.784, SD = 2.525) and post-survey (M=8.368, SD = 2.561) scores (t(184) = 3.489, p = .001, d = 0.230). The change in male scores was not significant. When comparing the pre-scores of males (M=8.446, SD = 2.743) and females (M=7.784, SD = 2.525) on that same scale before their first Arts & Bots experience, we see that males score significantly higher (t(360) = 2.393, p = .017, d = 0.251). However, following Arts & Bots, the difference is not significant, indicating that the gap between males (M=8.746, SD = 2.960) and females (M=8.368, SD = 2.561) was reduced. This means that the Arts & Bots experience helped female students catch up to their male peers in terms of understanding of the tasks involved in engineering careers.

Taken together the significant gender differences in enjoyment of the *Multidisciplinary or Creative* aspects of the project, increased *Confidence*, and increased awareness of *Engineering Careers* suggest that Arts & Bots' emphasis on creativity and expressiveness has achieved its goal of engaging a population frequently less engaged with technology.

TABLE I. SHORT ANSWER RESPONSES BY GENDER

"Did you enjoy this project? Why or why not?"		
Code Assigned	***Percent Male Responses (N=207)***	***Percent Female Responses (N=215)***
Fun or Enjoyable	33.8%	31.6%
Teamwork	15.5%	19.5%
Technical Learning	11.1%	14.4%
Enjoy Building	10.1%	10.7%
Multidisciplinary/Creative	2.4%	11.2%*
Novelty	6.8%	8.4%
Enjoy Arts & Crafts	0.5%	6.0%
Mixed or Neutral	1.0%	5.1%
Interest	3.9%	5.1%
Enjoyable or Good Challenge	5.8%	2.3%
"How did this experience change how you think about technology?"		
Code Assigned	***Percent Male Responses (N=161)***	***Percent Female Responses (N=174)***
Technical Learning	26.1%	25.9%
Fun	18.0%	20.1%
Appreciation for the Complexity of Tech.	11.8%	12.6%
Appreciation for the Broader Applicability of Tech.	8.1%	12.1%
Easy	5.0%	8.6%
No Change	12.4%	8.1%
Confidence	3.1%	6.3%

*Significant difference.

VI. CONCLUSION

Through our evaluation of the Arts & Bots project, thus far, we have grouped student outcomes around four themes: technical knowledge and skills, student dispositions, teamwork, and gender comparisons. Our results suggest that student technical knowledge and skills increase during Arts & Bots projects. On multiple choice scales, we saw significant pre/post improvement on systems engineering concepts and student understanding of engineering careers. Further, students frequently self-reported learning a variety of technical skills on all three post-survey short-response questions that we coded.

Our results from the student attitudes RAAS scales did not align with our hypotheses. Instead, we found that students had significant decreases in attitudes towards robotics and technology, including identity, curiosity, and learning potential. These quantitative results are in opposition to the students' self-reported enjoyment of the project, in which the large majority report they do enjoy it. One possible explanation is a novelty effect present before the first Arts & Bots experience, and this is supported by student responses. Another possible factor is that since we are eliminating student self-selection, it is reasonable that not all students would conclude that such projects are to their liking. Finally, it is possible that the relatively short but intense exposure to robotics and engineering received during Arts & Bots leads students to believe they have learned all they need to know about robotics and engineering activities instead of expanding their curiosity.

During our analysis, we also identified trends in student short answer responses that suggest the importance of teamwork in shaping the student Arts & Bots experience. *Teamwork* was frequently mentioned by students in response to questions both about their enjoyment of the project and the best thing they learned from the project. Other students described negative team experiences indicating that teamwork support has likely been inconsistent across Arts & Bots projects.

Finally, we compared the project experience across genders to assess our program goal of engaging all students. We found that female students had significantly more mentions of the combined *Confidence* / *Easy* category in response to the question "How did this experience change how you think about technology?" They were also significantly more likely than their male peers to mention enjoying the *Multidisciplinary or Creative* aspects of the project and had a greater increase in post-survey mean correct score when asked to identify engineering job tasks. This suggests that Arts & Bots is successfully achieving our goal of engaging both genders.

VII. FUTURE DIRECTIONS

Notably missing from this evaluation, is an analysis of student disciplinary knowledge gains within the integrated topic. This is an intentional omission due to the difficulty of developing valid assessments for each of the many disciplines chosen by teachers in this study and for analyzing those results collectively. However, as disciplinary integration is central to Arts & Bots, in the future, it would be interesting to investigate the effects of integration on student disciplinary knowledge.

Additionally, as we have been conducting Arts & Bots research within one school for greater than three years, we have within our evaluation collected data from single students across multiple projects and classes over multiple years. This will provide an interesting avenue of evaluation going forward through a longitudinal analysis. Finally, our analysis suggests an area of potential future development for Arts & Bots: namely the development of materials and training to aid teachers in shaping and guiding the teamwork experiences of students as they undertake Arts & Bots projects.

Since the Arts & Bots program began in 2006, it has demonstrated great promise in increasing student technological knowledge and skills and has been successful in eliminating student self-selection through integration with required non-technical classes. We look forward to further improving the Arts & Bots program and increasing the scope of our evaluation in the future.

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