Arts & Bots: Application and Outcomes of a Secondary School Robotics Program

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Abstract—**Arts & Bots combines intrinsically creative craft materials, common robotics components, a custom programming environment and teacher professional development to create a flexible robotics intervention for secondary school classrooms. In order to engage students underserved by other robotics programs, Arts & Bots is oriented to support the creation of collaborative expression-focused robots, as opposed to more commonly implemented competitive task-focused robot activities. Specifically, Arts & Bots targets integration into traditional non-technical classes, such as literature and history, to reach a broader base of students than would be enrolled in elective technology programs. This paper describes three classroom implementations, including a secondary school poetry project. By including Arts & Bots in these core courses, we expose diverse students to engineering education activities such as hands-on experiences with computer programming, prototyping, and the engineering design process. We present our outcomes grouped within two primary themes: first, in Technological Fluency, we present students' self-reporting of concepts learned, confidence with technology, and breaking of technology stereotypes; second, in Complementary Non-Technical Skills, we present other skills students learned by participating in the Arts & Bots program.**

Keywords—educational robotics; interdisciplinary education; technological fluency; secondary school engineering

I. INTRODUCTION

The diversity of new technological inventions is greatly affected by the creativity and background of technology developers. Considering the underrepresentation of women and minorities in STEM careers, it is evident that society is inadequately utilizing the creative capacities and diverse experiences that such underrepresented groups could contribute. In order to attract a wider diversity of students to pursue advanced training and careers in engineering, it is critical that students have pre-college experiences that allow them to practice engineering and help them to develop technological fluency.

Technological fluency is the ability to manipulate technology creatively and for one's own use; an idea espoused by our research [1] among many others [2] [3] [4] [5]. It is important to provide opportunities to develop technological fluency to all students, yet the current practice of pre-college engineering education frequently limits engagement with engineering to a narrow population. In secondary school, engineering-focused extracurriculars often utilize high-intensity, contest-driven challenges as motivational hooks for students inspired by competition [6] [7]. Engineering and technology classes in secondary schools are usually offered as elective classes for students with pre-existing interest in engineering and technology. Unfortunately, these current approaches fail to reach students who are unmotivated by competitions or are uninterested in technology for its own sake.

Our intervention, Arts & Bots is aimed to engage a more diverse population of students, including those unmotivated or uninterested in existing technology interventions, in engineering practice. We look to achieve this through a robotics program that is focused on expression and communication over competition and that provides a non-technology context for technology use. The robot hardware kit, which is the basis for Arts & Bots, is designed to promote expressivity by combining intrinsically creative and gender neutral arts and crafts materials with commonly used robotics and technology components. Through programs like Arts & Bots, we believe it is possible to encourage a different style of student engagement than the status quo for secondary school engineering education and thus possible to attract a more diverse population of students to engineering careers.

II. ARTS & BOTS OVERVIEW

The Arts & Bots program started in 2006 with the goal of exploring the educational impact of expression-focused technology experiences. The Arts & Bots program initially began as an extracurricular intervention which aimed to diversify the Computer Science pipeline by engaging 11 to 14 year old girls [8] [9] [1]. At that time, others were also developing similar extracurricular programs for engaging students who were not interested in traditional robotics programs and competitions, by providing connections to robotics through creative interests, like music, art, and storytelling [10].

Following our initial implementation phase as an extracurricular program, we transformed Arts & Bots into an in-school intervention in order to reduce participant self-selection. By designing the Arts & Bots kit to enable craft-based building followed by choreographic programming, we
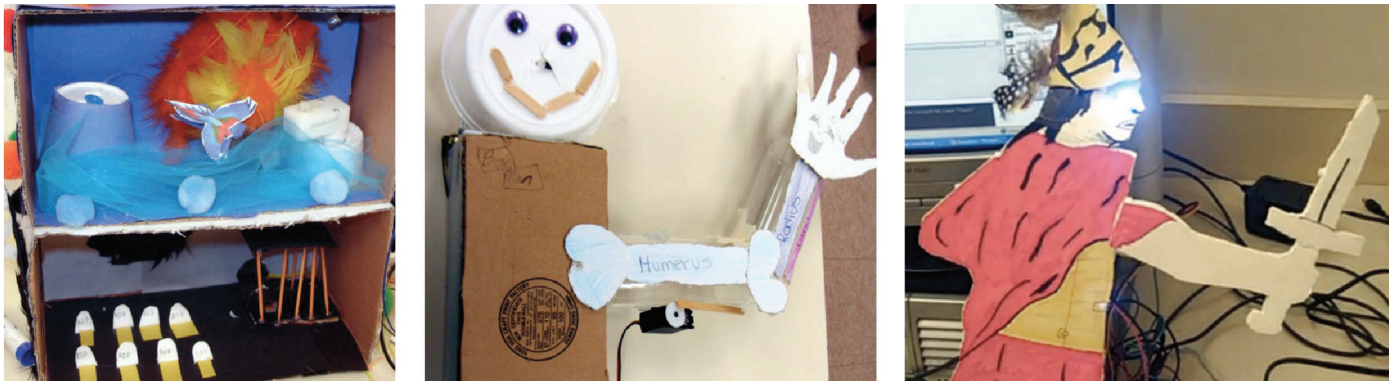
Fig. 1. Student built robots, from left to right, robot theater (I Know Why the Caged Bird Sings by Maya Angelou), arm model, and historical figure (Alexander the Great).

connected technological fluency to arts education, which is well-regarded and supported in school systems and by students who may not have strong prior experience with electronics. We focused efforts on integration with non-technical, core courses in order to engage students in engineering and programming practice who would otherwise avoid enrolling in a technical elective course or extracurricular activity.

The Arts & Bots hardware kit includes a large number of aesthetically-oriented outputs including DC motors, hobby servos, and tri-color LEDs along with various interaction-promoting sensors including IR distance, light, and sound level sensors. Craft materials are chosen by the educator to suit her desired project. By implementing affordances for sound, lights, and choreography, we enable Arts & Bots to be flexibly integrated into secondary school topics such as poetry. Additionally professional development training on Arts & Bots has repeatedly enabled teachers in such non-technological disciplines to directly implement Arts & Bots as expressive elements of their student assignments [11], enabling the summative evaluation of student attitudes and student knowledge gains as reported in this article. While prior publications have concentrated on the iterative participatory design of the Arts & Bots hardware [9] and software elements [12], this report focuses on the educational evaluation of Arts & Bots in 7th and 8th grade core disciplinary courses.

A. Arts & Bots Curriculum Examples

Through professional development, we train teachers to use the Arts & Bots hardware and software, and to develop their own project which integrates Arts & Bots with the goals of their discipline [11]. We provide three examples of this type of curricular project in different areas: poetry, health and history.

1) Poetry

The first example is a poetry project. Beginning in 2012, a small public, junior-senior high school began implementing Arts & Bots in their 7th and 8th grade Language Arts classes. In this class, teams of two to four students chose poems from a list preselected by the teacher for their vivid imagery. Over seven class days (roughly 14 contact hours), these students worked in groups to analyze the selected poem and design a robot theater (Fig. 1, left) which they build and program to represent their poem. Students recorded audio clips of themselves reading the poem and incorporated these clips into

the programs they wrote. The class was jointly instructed by the Language Arts and Gifted Support teachers.

2) Joints and the Musculoskeletal System

The second implementation example took place in a health and physical education class. Two 7th grade teachers taught Arts & Bots to a combined health and physical education class on joints and the musculoskeletal system beginning in 2014. Teams of students created models of human joints (Fig. 1, center) which they could "personalize" with clothing and accessories. Students chose a joint for their project: knee, shoulder, or elbow. Teachers provided a limited number and variety of materials with an emphasis on using recycling and recycled material. The project covered 15 class periods (roughly 12.5 contact hours).

3) Historical Figures

The last example is from a technology education teacher who implemented an Arts & Bots project with 7th grade students. The project was spread over the course of the school year (roughly 20 contact hours) beginning in 2010. The technology education teacher integrated content in history, English, science, and math classes that were co-taught with each content teacher respectively. Students selected a historical figure from a list provided by the history teacher (e.g., Hercules, Alexander the Great, Pharaoh Hatshepsut). In history class, the students researched the life of their chosen figure. In English class, students wrote a biography from the perspective of their individual. Finally, with support from the math and science teachers, students built robotic models of their historical figures (Fig. 1, right) and programmed them to act out the biography.

III. METHODS

A. Hypotheses

We wish to understand the ways in which creative robotics activities within a disciplinary context impact student learning, and in particular, how student technological fluency is affected by this inclusive approach to technology exposure. Technological fluency itself is governed by two factors: student attitudes toward technology, and student technical knowledge. Each form of change is insufficient by itself in catalyzing a shift in the overall student-technology relationship. Empowered attitudes are required for students to apply

knowledge. Knowledge is required for students to be effective in acting on their attitudes. Thus, we propose two specific hypotheses relating to enablers of student technological fluency:

1. Arts & Bots increases student grounding of technical knowledge and technical skills.

2. Arts & Bots increases student motivation and confidence to engage with technology.

In addition to fluency-centered hypotheses, an important goal for the Arts & Bots pilots stems from our desire support the technology of all students. We believe that the incorporation of creative robotics into disciplinary core courses has the capability to attract a more diverse student population to technology and, thus, to a pathway toward technological fluency. Our third hypothesis relates specifically to the nature of inclusiveness achieved with the Arts & Bots program:

3. Arts & Bots engages a broad demographic of participants, across gender and across prior technological exposure.

If these three hypotheses are supported by our evaluation, then we believe that Arts & Bots successfully meets the need for an intervention which improves the technological fluency of a broader population of students through a different style of student engagement than the current pre-college engineering education status quo.

B. Assessment Tools

We organized the evaluation of technological fluency into two primary surveys reflective of our hypotheses: Student Knowledge with Respect to Technology (Knowledge) and Student Attitudes with Respect to Technology (Attitudes). We also collected basic demographics information from students, including race, age, grade level and gender for addressing the broadening demographics hypothesis. Student learning and attitudes were assessed through pre and post surveys given to students before and after their Arts & Bots project respectively. A small subset of students was interviewed following completion of their Arts & Bots project.

1) Knowledge Survey

The Knowledge Survey consists of six short answer questions, nine multiple-choice hardware component questions phrased as analogies, six multiple choice software questions, and ten multiple choice systems engineering questions. The short answer questions were slightly different between the pre and post-test version. The systems engineering questions are adapted from [13] and include 10 items describing actions of devices and subsystems. The students were prompted to indicate whether each action is an "Input", "Output" or "Processing" of the system (Table I). This paper presents results from two short answer questions and the systems engineering questions. Hardware and software multiple-choice questions continue to be tested and refined.

2) Attitudes Survey

The student Attitudes Survey consisted of 7 short answer questions and 35 Likert-type questions. The short answer questions were slightly different between the pre- and post-test

Multiple Choice Questions	Details	
	Number of Items	Answer Choices
Attitude Scales: Please select the answer that shows how you feel right now about the statement. There are no right or wrong answers, just be honest.	35	NO! no Neither yes or no yes YES!
Systems Engineering Scale [13]: 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.	10	Input Output Processing

version. The Likert-style questions have students rate agreement with various attitude statements with grade level appropriate options: "YES!", "yes", "neither yes or no", "no", and "NO!" (Table I). The Likert-style questions fall into four attitude subscales: Interest (9 items), Motivation (9 items), Curiosity (8 items), and Confidence and Identity (9 items). This paper presents results from three short answer questions and from the Likert-style questions.

C. Demographics

In this paper, we present data and analysis from 7th and 8th grade students experiencing their first Arts & Bots project. Data were collected from six schools: five public and one independent; a mix of rural (n=3), suburban (n=2), and urban (n=1). Data were collected in 13 separate classes. These classes included six 7th grade classes covering: Accelerated Language Arts, Advanced Math, History, and Technology Education; and seven 8th grade classes covering: Academic and Accelerated Language Arts. Data were collected between November 2010 and April 2014.

The number of students in the data samples below varies slightly due to a number of factors. First, student absentees resulted in unequal numbers of Knowledge and Attitude Surveys as they are sometimes applied on consecutive class days depending on class structure. Second, incomplete data collection by teachers led to entire classes having only pre- or post- surveys collected. Finally, our survey tools undergo regular refinement and modification of wording thus 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) were participating in their first Arts & Bots project. This led us to exclude data collected from 19 twelfth grade students who were considered outside the target class level and data collected from 6 seventh grade and 34 eighth grade students who had prior Arts & Bots project experiences.

There are Attitudes Survey data from 139 students in 7th grade and data from 73 students in 8th grade. Of those, 98 seventh graders and 55 eighth graders completed matching pre- and post- Attitudes Surveys. There are Knowledge Survey data from 140 students in 7th grade and data from 89 students in 8th grade. Of those, 100 seventh graders and 44 eighth graders completed matching pre- and post- Knowledge Surveys.

D. Analysis

Students were assigned unique subject numbers, and names were replaced by subject numbers throughout the data. The analysis methods used for the three types of survey items (short answer items, Likert-type attitudes items, and systems engineering items) are described below.

Short Answer Coding: Open-ended questions were coded independently by two coders, each an expert in robotics. Survey responses were randomly assigned survey ID numbers to make coding blind to student grade level and whether responses were from pre- or post- surveys, when possible. Responses could be assigned multiple codes if they expressed multiple unique ideas without overlap. Unless otherwise noted, coding was done on the full set of data, and inter-rater reliability was calculated for this complete set (Table II). The top response codes are provided in tables for the following four questions: "What was the best thing that you learned during the project?" (Table III), "Did you enjoy doing this project?" (Table IV), "How did this experience change how you think about technology?" (Table V), and "Should other students have this experience?" (Table VI).

Attitude Scales: Analysis of the Likert-type questions was completed using binary scoring to eliminate any assumption of equal spacing between responses while reflecting the general attitude of the student. For this analysis, we used the binary scoring: (1) positive technology attitudes responses ("YES!" and "yes") and (0) non-positive responses ("NO!", "no" and "neither yes or no"). The item scores are inverted for negatively phrased questions: (1) negative technology attitudes responses ("NO!" and "no") and (0) non-negative responses ("YES!", "yes" and "neither yes or no"). As an item-wise analysis, we calculated a McNemar test for each Likert-type question, to test the hypothesis: the proportion of students responding positively to the statement in the pre-test was different from the proportion of students responding positively to the statement in the post-test.

Systems Engineering Scale: For each of the 10 multiple-choice questions, we assigned a score of 0 (incorrect) and 1 (correct) for each participant response. Each participant could then be assigned a systems engineering subscore on a scale from 0 to 10 representing the number of items he or she answered correctly. We then tested the hypothesis: the distribution of the student scores was different between the pre-test and post-test. The score distribution had an asymmetrical distribution where the number of students achieving a maximum score on the evaluation prevented a normal distribution. This indicated that the appropriate statistical test for our hypothesis was a Wilcoxon Signed Ranks Test, a non-parametric test for comparing the median score of the distributions.

IV. Outcomes

Through the data and analysis described, we identified two primary outcome themes: Technological Fluency and Complementary Non-technical Skills. Technological Fluency covers technical knowledge gains, confidence, and changes in technology stereotypes. Complementary Non-Technical Skills encompasses teamwork, perseverance, and

TABLE II. INTER-RATER RELIABILITIES FOR OPEN-ENDED QUESTIONS

Open-Ended Questions	Coding Agreement	
	Inter-rater reliability % agreement	*Number of codes compared*
How did this experience change how you think about technology? (post)	91.0%	N=199
Did you enjoy doing this project? Why or why not? (post)	84.4%	N=244
Should other students have this experience? Why or why not? (post)	84.4%	N=237
What was the best thing that you learned during the project? (post)	91.0%	N=210
What parts did Evan use to make the flower? (pre & post)	100.0%	N=193[a]

[a.] Inter-rater reliability was calculated on a subset of 193 responses out of a total of 359 responses.

several other personal skills. All student quotes included below are provided verbatim.

A. Technological Fluency

1) Learning about Robotics

As we hypothesized, students self-reported learning about robotics, technology, computers, programming, specific robotic components used in the class, and engineering design concepts across many different open-ended questions. For the following three open-ended questions, learning about technology was one of the top three most common student responses to each question. When asked "What was the best thing that you learned during the project?", the majority of students (56.8%, N=139) described a technological learning gain. For example one student said "The best thing was just basically programing the hummingbird. When you tell something to do something and it works it feels amazing," (8th grade male, academic language arts). When asked "Should other students have this experience?", 17.7% of students (N=130) said other students should because they would learn about technology. When asked "Did you enjoy doing this project?", 16.8% of students (N=131) reported that they enjoyed the project because they learned about technology. For example, a student said "YES! I didn't know much about robotics before this project. I definitely feel more educated about robotics now than I did before this project. It was a GREAT learning experience!" (7th grade male, accelerated language arts). In response to the question "How did this experience change how you think about technology?", 13.2% of students (N=129) reported that they learned something new about technology. For example, one student reported "i understand it much more now!!!" (7th grade female, accelerated language arts). These self-reported learning gains about specific and more generalized technology knowledge and skills are supportive of the hypothesis "Arts & Bots increases student grounding of technical knowledge and technical skills."

In addition to self-reported technical learning, an open-ended knowledge question, designed to measure student understanding of robotic systems and components, indicated significant technical learning gains. Students watched a short video of a craft-based robotic flower catching a ball in its petals. After watching the video, they were asked "What parts did Evan use to make the flower?". Student short answer responses were coded as being: 0) video could not be played, 1) I don't know, 2) a non-technical answer, 3) a conceptually

correct technical answer but using incorrect terminology, or 4) a correct technical answer. Non-technical answers included craft materials, nonspecific technical parts (i.e. "robot parts", "knob"), or structural parts not contributing to the robot's function (i.e. "metal"). Correct technical answers included terms such as "servo motor", "circuit board", "gears" and "pressure sensor". Correct technical answers that were misspelled were coded as correct. Sixty-nine students were unable to play the video on school computers in either the pre- or the post-survey and were excluded from analysis. A McNemar's Test indicated there was a significant increase in the proportion (47.2% pre-, 95.5% post-) of students who gave a technical response, as shown in Fig. 2, to the question on the post survey, χ^2 (1) = 41.09, n = 89, p <.0001. This result supports the technical knowledge and skills hypothesis as these students demonstrated both increased knowledge of robot components and increased skill in describing a novel technological system.

Another part of the Knowledge Survey, the qualitative Systems Engineering Scale, measured significant learning gains between the pre- and post-surveys as shown in Fig. 3. A Wilcoxon Signed-ranks test indicated that the Systems Engineering knowledge subscore post-test (median = 8) was significantly improved over the Systems Engineering knowledge subscore pre-test (median = 7), Z = -4.820, p < .0001, r = .41, n = 138. These increases indicate not only an improved understanding of robotics, but also improvements in student understanding of the systems engineering concepts of inputs, outputs, and processing. This finding of increased technology systems engineering further supports the knowledge and skills hypothesis.

On two attitude Likert-type responses related to learning technical knowledge, there were significant differences found between the pre- and post-surveys. On the statement, "I am curious about how robots work", McNemar's Test indicated there was a significant decrease in the proportion of students who agreed with the statement on the post-survey, χ^2 (1) = 4.84, n = 108, p = .043. In addition, a McNemar's Test indicated there was a significant decrease in the proportion of students on the post survey who agreed with the statement "I would like to learn more about robotics", χ^2 (1) = 7.2, n = 108, p = .012. At first glance, these decreases in curiosity seemed discouraging; however in combination with the measured and self- reported gains in knowledge with respect to technology, we hypothesize that for some students the project was adequate
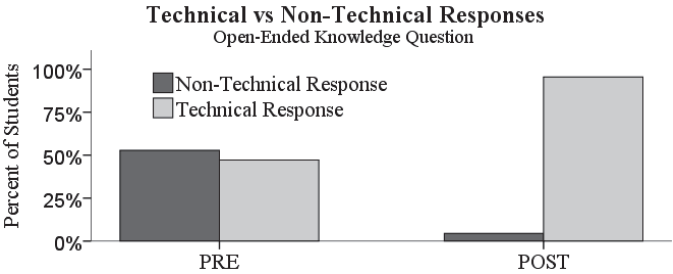

Fig. 2. Percent of students giving non-technical and technical responses on the open-ended knowledge question: "What parts did Evan use to make the flower?" (N=89).

in fulfilling their desire for learning about technology. This interpretation indicates that future implementations may be improved by placing more emphasis on the expansive and growing field of robotics and introduce Arts & Bots to students as a fragment of that field in order to seed new curiosity. In addition to this reported satisfaction of learning, we saw corresponding improvements in student confidence, described in more detail below.

2) Improved Confidence

Given the self-reported and measured learning gains in technology and robotics, it is not surprising to see that students had increases in confidence with technology as well. On the Confidence sub-scale Likert-type item, "I am not good at making robots" a McNemar's Test indicated there was a significant increase in the proportion of students who disagreed with the statement on the post-survey, χ^2 (1) = 5.7, n = 108, p = .024. That is to say that the number of students who took a stand for their own abilities making robots increased. This interpretation is supported by findings from the earlier extracurricular Arts & Bots pilot, which also found an increase in student confidence with respect to robots [4], as well as by short answer responses described below.

Students answering the question, "How did this experience change how you think about technology?", mentioned that they felt more confidence in their technology skills after the project (5.4% of students, N=129). Some students noted increased confidence in programming, for example, "I always thought technology was far too complex for me to ever have even a basic understanding of programming and how it works. I now know that I will be able to learn basic programming skills if I choose to do so" (7th grade male, technology education). Other students had increased confidence working with the hardware,
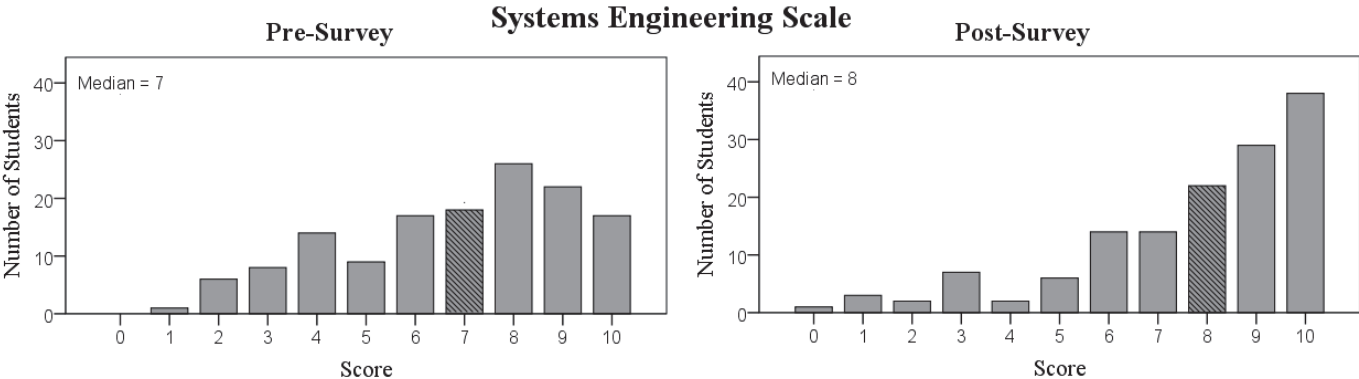

Fig. 3. Distribution of student scores on the 10 item Systems Engineering Scale, median score bar indicated. (N=138)

TABLE III. WHAT WAS THE BEST THING THAT YOU LEARNED DURING THE PROJECT? RESPONSE SUMMARY

What was the best thing that you learned during the project?	Percent of Students N=139
Technical Learning	56.8%
Teamwork (positive indication)	22.3%
Multidisciplinary Integration	6.5%

a. Categories representing less than 4.5% of students not shown.

TABLE IV. DID YOU ENJOY DOING THIS PROJECT? WHY OR WHY NOT? RESPONSE SUMMARY

Did you enjoy doing this project? Why or why not?	Percent of Students N=131
Yes - Technical Learning	16.8%
Yes - Enjoyed Technology	13.0%
Yes - Novelty of Experience	13.0%
Yes - Teamwork (positive indication)	13.0%
Yes – Fun Experience	12.2%
Yes - Enjoyed Building	9.9%
Yes - Vague Learning Gain	8.4%
Yes - Creative	5.3%
No - Teamwork (negative indication)	4.6%

b. Categories representing less than 4.5% of students not shown.

such as, "I think I got a lot better at learning how to hook things up to the humming bird, and it taught me not to be afraid of messing up" (8th grade female, academic language arts). Beyond confidence in specific technical skills, for some students, the experience also resulted in a shift in identity with respect to technology. For example, one student said "it made me feel more connected and confident using the robotic elements it made the technology feel more accessible instead of just something really smart people or nerds do" (8th grade female, accelerated language arts). This finding of increased confidence with technology in part supports the second hypothesis "Arts & Bots increases student motivation and confidence to engage with technology."

3) Breaking technology stereotypes

One interesting aspect of the Arts & Bots experience is the way it challenged stereotypes students held about technology. When asked "How did this experience change how you think about technology?", 17.8% of students (N=129) reported that they found that it was harder than they expected. For example, one student reported "This experienced changed how I think about technology because I thought all technology was easy for me. After completing this project I thought this was actually difficult." (7th grade female, accelerated language arts). This was the highest-scoring sub-code for this question. However, we do not believe this simply meant that students found the project to be too hard. Instead, we believe that students gained a more realistic understanding of the challenges involved in complex, real world engineering design problems. Examining all students in our selected set (7th and 8th grade on their first Arts & Bots experience) with post-survey results, 23 students (17.8%, N=129) said that they discovered that technology was harder than they thought. Of these 23 students, 87.0% reported enjoying the project, 13.0% reported they did not enjoy the project. Stated another way, although students found technology more challenging than they expected, it did not indicate that students didn't enjoy the project. In contrast, 11.6% of students (N=129) reported that they found that technology was less challenging than they expected. For example, one student said "After this experience, I thought that technology wasn't as confusing as I thought it would be and that it wasn't only an amazing learning experience but also a fun project." (7th grade male, accelerated language arts). Since many students answered the question, "How did this experience change how you think about technology?", with statements about how technology was either harder or easier than they had expected suggests that first-hand experience helped the students develop a more realistic metric of the complexity of technology development. This realistic metric of complexity is yet further support of the hypothesis "Arts &

Bots increases student grounding of technical knowledge and technical skills".

Students also reported an increased appreciation for technology. The second most common response to "How did this experience change how you think about technology?" was from 17.1% of students (N=129) who reported that it increased their appreciation for technology. Responses coded as increased appreciation could include appreciation for the complexity of technology, understanding of applications of technology in everyday life, or reporting a new perspective on technology. For example, one student said "This experience makes me appreciate the people that do computer programming for a living." (7th grade female, accelerated language arts), and "This experience changed my thought on technology because I used to think that technology was only cell phones and gadgets like those, but now I know that there is more to technology than meets the eye." (7th grade female, accelerated language arts). Students mentioned increased appreciation for technology in their responses to other questions as well, though in smaller proportions: "Should other students have this experience?", 2.3% (N=130); and "What was the best thing you learned during the project?", 2.2% (N=139). The reported increase in appreciation for technology reflects student statements towards valuing the role technology plays in their lives and the world. Value is a contributing factor for motivation and thus these findings are supportive of the hypothesis on motivation and confidence.

Not surprisingly, given the creative and interdisciplinary nature of Arts & Bots projects, students also reported learning about creative uses of technology. 6.5% of students (N=139) mentioned the multidisciplinary nature of technology in response to "What was the best thing that you learned during the project?". For example, one student stated "Poetry can be very difficult to understand, but using robotics and creating a visual view of the poem can help you understand it more." (8th grade female, accelerated language arts). When asked "Did you enjoy doing this project?", 5.3% of students (N=131) reported that they enjoyed the project because it was creative. For example, a student said "Yes, I like how people can be creative with their minds sice [since] there are so many options of

How did this experience change how you think about technology?	Percent of Students N=129
More challenging than I thought	17.8%
Gained appreciation for technology	17.1%
Technical Learning	13.2%
Less challenging than I thought	11.6%
No change reported	8.5%
Increased enjoyment of technology	7.8%
Increased perseverance	5.4%
Increased interest in technology	5.4%
Increased confidence with technology	4.7%
Found technology to be fun	4.7%

c. Categories representing less than 4.5% of students not shown.

Should other students have this experience? Why or why not?	Percent of Students N=130
Yes – Fun Experience	33.1%
Yes – Career/Future Benefits	18.5%
Yes - Technical Learning	17.7%
Yes - Vague Learning Gain	15.4%
Yes – Teamwork (positive indication)	10.0%
Yes – Novelty of Experience	6.2%

d. Categories representing less than 4.5% of students not shown.

materials to choose from." (8th grade male, accelerated language arts). This recognition of technology as a creative medium is aligned with both the definition of technological fluency as creative application of technology and the Arts & Bots program goal of providing a robotics intervention that is focused on creativity and self-expression.

Finally, students reported that Arts & Bots can influence perspectives on technical careers or that the learning is applicable to students' futures. When asked "Should other students have this experience?", 18.5% of students (N=130) said yes, because it would help their future or career. For example, one student said "I think other students should have this experience because it could increase your ability to one day go to college and maybe also have a career in technology." (7th grade female, accelerated language arts). This was the second highest response category for this question, superseded only by yes because it was fun (33.1%, N=130). This demonstrates that students value the role that technology may play in the future lives and careers of their peers and believe that Arts & Bots contributes positively to this role.

In summary, student responses show that students' understanding of the complexity of engineering design and technical projects became more grounded in reality, students came to appreciate technology in the larger world around them, students came to see that technology could have creative applications, and they considered the benefits of what they had learned from the project for their lives in the future.

B. Complementary Non-Technical Skills

1) Teamwork
Beyond the primary goal of improving the technology skills, knowledge, and attitudes that comprise student technological fluency, we also saw evidence of students developing non-technical skills. One of the most prominent non-technical skills mentioned by students in the short answer responses was teamwork and working with their peers. The learning of teamwork skills was the second most common code (22.3% of students) surpassed only by learning about

technology (56.8%) when asked "What was the best thing that you learned during the project?" (N=139). For example, one student said they learned "Not to blame anyone for their mistakes because [you] will end up making at least one and you would not like to be blamed" (7th grade female, accelerated language arts). Teamwork appeared in the responses to other questions as well. For "Did you enjoy doing this project?", 13% of students (N=131) reported that they enjoyed the project because they enjoyed the teamwork. When asked "Should other students have this experience?", 10.0% of students (N=130) said yes because they would practice teamwork. For example, a student replied "yes because it changes your thinking on how you can do projects and work with other students" (7th grade female, accelerated language arts) and "Yes I think there are a lot of people my age that would like this, it brings both tech savvy people and people who can work well with their hands together." (8th grade female, academic language arts). This trend is especially notable because teamwork is not explicitly addressed by either the Attitudes or Knowledge surveys.

In addition to these self-reported teamwork learning gains, we also saw a decrease in the number of students who agreed with the statement "It's important to me to know more about technology than most people" following Arts & Bots. A McNemar's Test indicated this was a significant decrease in the proportion of students, $\chi^2 (1) = 6.7$, n = 108, p = .014. At first look, this decrease in the perceived value of technological knowledge seems discouraging; however we believe that the relative value students apply to their knowledge and skills is changed through the teamwork aspects of the Arts & Bots project. This interpretation is supported by some student responses to open ended questions, for example "the best thing i learned in this projected [project] was that everybody did something to help the group so it would be teamwork" (8th male, academic language arts) and "That you need to make sure everyone is working and following along to the best of their ability so you get it done quickly." (7th grade female, accelerated language arts). Student statements like the ones above directly support the idea that students not only learned the value of communication and teamwork but came to value the contributions of their teammates towards successful completion of a technical project of this scope.

Teamwork was such a large component of student experiences with Arts & Bots, we also see reports from students who had negative teamwork experiences. The highest

negative response code for "Did you enjoy doing this project?" was negative teamwork (4.6% of students, N=131). While most students mentioning teamwork found it enjoyable or beneficial, some students had negative teamwork experiences. Anecdotal reports from teachers suggest that teamwork is a very challenging area for middle school students, thus seeing both positive and negative reactions to teamwork is not surprising.

The prevalence of teamwork in the short response questions can be explained by the integral role that teamwork plays in Arts & Bots projects. The scope of these Arts & Bots projects was such that no single student could complete the project on their own. In addition, the complex, interconnected nature of an engineering design projects requires students to collaborate closely with each other, rather than simply working in parallel. In short, Arts & Bots forces students to practice teamwork.

2) Other Skills

While teamwork was the most prominent non-technical skill reported by students, several other skills also surfaced across the open-ended question responses. Perseverance was the most notable of these with 5.4% of students (N=129) reporting increased perseverance with technology in response to "How did this experience change how you think about technology?". Responses stating that the project or technology was challenging but rewarding or worthwhile in the end were coded in to this category, for example, "…. The use of the different robot parts was challenging but very rewarding in the end, but not as challenging as expected." (8th grade male, accelerated language arts). Perseverance surfaced in response to other questions in smaller proportions: "What was the best thing that you learned during the project?", 2.9% (N=139); "Should other students have this experience?", 2.3% (N=130); "Did you enjoy doing this project?", 0.8% (N=131). Time management and problem solving skills were reported by a few students. In response to "What was the best thing that you learned during the project?", 2.9% of students (N=139) reported time management. In response to "Should other students have this experience?", one student reported problem solving skills, saying "yes, it helps with team work and problem solving skills." (8th grade female, accelerated language arts). These skills and dispositions were not explicitly addressed by the hypotheses, the professional development, or the evaluation tools and thus these results suggest an interesting avenue for future work.

V. FUTURE DIRECTIONS

In the future, we plan to continue to: 1) expand upon the outcomes discussed above, as not all outcomes could be reported within the scope of this paper; 2) make improvements to the Arts & Bots system; and 3) explore new areas of evaluation. We plan on expanding upon our findings related to the development of teamwork and other non-technical skills by developing professional development and curriculum materials designed to help Arts & Bots teachers maximize these complementary gains. We will also seek to develop items for measuring these non-technical gains in more detail. We are also interested in the development of evaluations related to the multidisciplinary nature and curricular integration of Arts & Bots to help assess the impact that Arts & Bots has on student learning of the core discipline, e.g., poetry.

While we have done analysis on the data from the full population of the Arts & Bots students, we would be able to gain more insight by comparing subpopulations. For example, in order to address our program goal and hypothesis of "engaging a broad demographic of participants," it will be critical to further consider the knowledge and attitudes outcomes from the experience by different genders and by students with different experience levels. It will also be interesting to do further analysis of the differences of outcomes between the different student grade levels in order to help inform teachers in the selection of learning goals that can be achieved with this and similar projects in their particular classes. Longitudinal evaluation of students taking multiple Arts & Bots courses provides another interesting avenue for future work.

VI. CONCLUSIONS

We presented here results from the middle school creative robotics project Arts & Bots. The goal of the Arts & Bots program was to increase the technological fluency of middle school students. Evidence for this goal was found in student self-reported learning and enjoyment of the creative aspects of technology through participation in Arts & Bots.

Our hypotheses for evaluating the Arts & Bots program were:

1. Arts & Bots increases student grounding of technical knowledge and technical skills.

2. Arts & Bots increases student motivation and confidence to engage with technology.

3. Arts & Bots engages a broad demographic of participants, across gender and across prior technological exposure.

The first hypothesis was supported by student self-reported technical learning, significant improvement in technology component identification, significant increases in understanding of systems engineering concepts, and short answer responses demonstrating the grounding of technology concepts through first-hand experience.

The second hypothesis was supported by outcomes of self-reported confidence gains, an increase of students disagreeing with "I am not good at making robots", and self-reported increases in student appreciation of the real life applications of technology.

The third hypothesis is still being evaluated and as described in the prior section, will be the subject of future work. Outside of the original hypotheses, we also saw strong self-reported outcomes related to teamwork, which warrant further explicit evaluation and augmentation thorough future program development.

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