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Arts & Bots: Techniques for distributing a STEAM robotics program through K-12 classrooms

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***Abstract* – Arts & Bots is a craft-based robotics program focused on expression and creativity in the service of improving K-12 student technological fluency. In this paper, we describe how we transitioned Arts & Bots from an out-of-school program to a successful classroom tool applicable to many school subjects. We focus specifically on partnerships with teachers and professional development strategies.**

Index Terms – educational robotics, interdisciplinary curricula, professional development, STEAM

INTRODUCTION

Arts & Bots (originally known as Robot Diaries), began in 2006, with the idea to develop an after-school robotics and technology activity that would appeal to audiences typically underrepresented in STEM education. Early on, we focused specifically on middle school girls after a number of studies indicated that female participation in STEM drops off significantly between 7th and 8th grade [1]. The initial aim of the intervention was to promote technology fluency, defined as the ability to manipulate technology creatively and for one's own use, within these underserved groups [2]. To accomplish this, Arts & Bots provided lessons and a kit incorporating craft materials, flexible robotic hardware components, and a custom software environment [3] that empowered students to create tangible interactive robotic sculptures. Other popular educational robotics initiatives [4][5] emphasize task completion goals in high intensity, competitive environments. In contrast, Arts & Bots aims to be creativity-focused and inclusive of students unmotivated by the aforementioned programs. These initial concepts and components for Arts & Bots were developed through a series of participatory design workshops with middle school girls in after-school and home-school settings [6]-[10]. One of the greatest challenges in these out-of-school settings was that of overcoming self-selection bias in program enrollment. The Arts & Bots project has the most potential to increase student technological fluency when reaching those students who are unlikely to choose elective robotics and engineering activities out of school. To mitigate the out-of-school self-selection issue, Arts & Bots was reframed to fit into K-12 classroom environments with a special emphasis on core classes that would be required for all students.

Creating a robotics program that can be integrated into core coursework presents a unique challenge. In order for teachers to implement the program in their classrooms, the technology must support and enhance the educational goals within the discipline (e.g., world history or biology) and must meet relevant learning standards. In addition, for the program to achieve widespread adoption, it should be flexible enough to adapt to the variety of resource and scheduling constraints found in schools. Simultaneously, the program should permit easy implementation by teachers regardless of technical skill level and access to outside technical support.

To achieve these goals, we have developed Arts & Bots as a flexible tool for teachers rather than a fixed curriculum. We collaborate with teachers, training them in the use of the Arts & Bots hardware and software and empowering them to become innovators by writing their own curricula that weaves technology into their classroom lessons. In this paper, we describe the Arts & Bots classroom integration process that has led to its inclusion in more than 21 school districts in Pennsylvania and West Virginia since 2010.

PROFESSIONAL DEVELOPMENT

In order to empower educators to create and implement their own curriculum, we refined Arts & Bots professional development through the piloting of a teacher residency program and a graduate course for educators. These ultimately led to the creation of a reproducible, streamlined professional development workshop structure. This progression is described below.

Teacher Residency

Following the initial out-of-school participatory design phase, and recognizing the benefits and challenges of working in schools, we enlisted the help of two teachers in the form of a paid summer residency program. The goal of this residency program was to understand if and how Arts & Bots could fit into classroom environments. Over the course of the six-week residency, the teachers worked in close partnership with developers to learn how to use the hardware components and software environment, built several Arts & Bots robots, developed early Arts & Bots lesson plans for classroom use, and tested their curricula in mock-classrooms. Each teacher then piloted their curricula in their classes during the subsequent school year. During these pilot classes, teachers provided us with the feedback necessary to improve the functionality and ease-of-use of the hardware and software.

Graduate Course for Educators

The following summer we offered a six-day graduate level short-course called "Educational Robotics for the

Classroom". During the course, eight enrolled teachers had an immersive educational robotics experience with the newly updated Arts & Bots hardware and software through the creation of multiple Arts & Bots robots. Through this experience, the teachers were able to provide additional usability feedback on the technology to help shape the ultimate refined program. Additionally, the teachers attended lessons on robotics programs available for classroom use; toured robotics research labs; and developed numerous Arts & Bots lesson plans for a variety of subjects. Educators paid tuition to enroll in the course and received CMU graduate credit upon completion. Completing the course required that the teachers create a complete, ready-to-implement lesson plan, incorporating relevant learning standards and rubrics for assessment. The goal of this course was to understand if offering graduate credit would attract more teachers and to help us distill the key knowledge and skills required for successful classroom implementation.

Professional Development Workshops

Following the residency and graduate course pilots, participating teachers successfully implemented their developed curricula with students, demonstrating that Arts & Bots could be applied to classroom settings and providing model curricula in a diverse set of disciplines. Those successes and model curricula were documented via an online blog where teachers were able to upload lesson plans and contribute photos and anecdotes about their Arts & Bots experiences. These examples serve as both models and inspiration for future educators and reduce the need to support curricula development during structured professional development time. Armed with a completely mature and commercially available hardware kit as well as a significantly improved software environment, we consolidated our training materials into a four-hour workshop that could be offered in a single evening or weekend session. The workshop covers online curriculum examples; the Arts & Bots hardware components; the visual programming environment; building, programming, and sharing a complete robot; and a debriefing discussion.

We found that demand for the course, and thus the potential for expansion, is directly related to course length and cost. There was a much greater demand and interest in Arts & Bots workshops than was expressed for the longer training, and due to the decreased overhead involved in running the shorter workshops, we were able to offer them more frequently (roughly quarterly). Between December 2011 and December 2012 we have offered six workshops through the CREATE Lab at Carnegie Mellon University and nine workshops through the CREATE Lab Satellite at Marshall University in West Virginia. One hundred and twenty seven educators have learned how to use Arts & Bots through these workshops. These educators teach K-12 students a wide variety of subjects including geography, math, history, anatomy, art, English, and physical science. Some examples of classroom implementations by teachers who have attended the workshops include studying angles in pre-K math, designing alien cultures in fifth grade social studies, creating pop-culture personalities in a middle school art class, and designing elaborate robots in high school pre-engineering.

Important Aspects for Success

After running multiple workshops, we have identified several key aspects of a successful Arts & Bots training session. As a robotics program, the diverse teachers implementing Arts & Bots must be able to teach both hardware and software engineering. While we provide direct instruction on all of the hardware components available in the kit, teachers must experience the challenges of constructing a robot from craft materials first-hand. Thus in each workshop, educators are challenged to build a robot around a given theme (e.g., "In a library") or to build a robot they envision their students creating. The challenge of transferring a vision to a functioning tangible device involves many unexpected design and practical fabrication hurdles. Building a complete robot provides insight into these challenges, which allows the educators to gauge the difficulty of projects and time required for their curricula, and to gain practical experience manipulating the Arts & Bots hardware and craft materials, whatever their prior engineering experience.

Through experimenting with several different sequences of instruction, we have found that it is important for the educators to understand the full capabilities and limitations of the Arts & Bots programming environment in order to inform their expectations before building their robot. However, the programming environment interface requires that a physical robot be available to use the software. We address this chicken-and-egg problem by first walking participants through the creation of a "mini-bot" which is simply a servo with an attached LED. The mini-bots are then utilized by all the teachers while learning to use the programming environment. They are then able to incorporate this programming knowledge during the design and construction of their main robot, eliminating many common misconceptions that occur when programming is taught after robot construction.

One final aspect of the workshops is that, as much as possible, we encourage educators to bring their own laptops. While the workshops would perhaps run more smoothly if we used pre-configured and tested computers, we feel that the experience of installing the software is valuable for participants if they truly plan to implement Arts & Bots in their schools. While the installation process is quick and easy for most participants, some laptops have settings that require additional debugging and this gives educators first-hand experience working through technical challenges under the guidance of experts. Many school-owned computers are configured to protect the school network and may interfere with the operation of the programming software. Identifying these barriers upfront allows us to find solutions before they interfere with class schedules and helps to identify school technology needs, informing software design requirements.

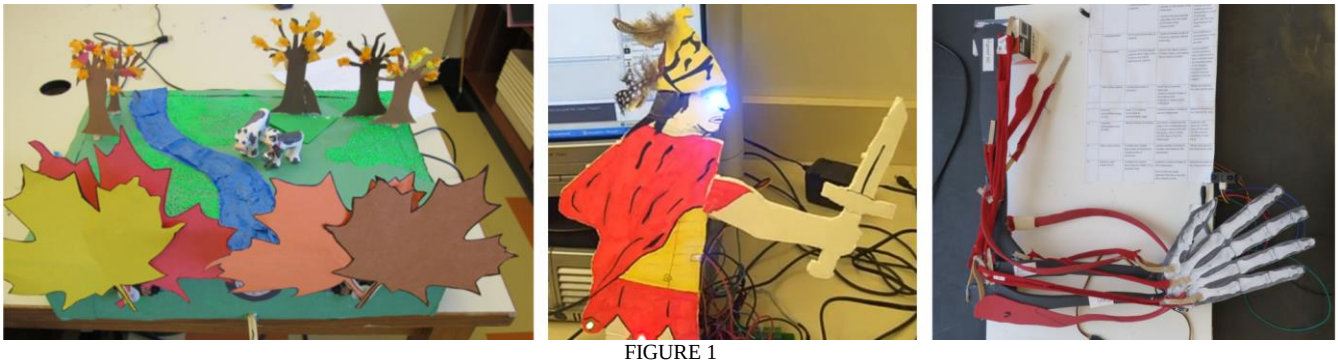

FIGURE 1
STUDENT BUILT ROBOTS, FROM LEFT TO RIGHT, POEM THEATER (THE PASTURE BY ROBERT FROST), HISTORICAL FIGURE (ALEXANDER THE GREAT), AND ANATOMICAL ARM.

CLASSROOM EXAMPLES

The Arts & Bots program provides numerous enhancements to classroom experiences that are aligned with modern educational standards and learning science theories. Extended-length, ability-appropriate projects, like Arts & Bots, help students to develop perseverance by necessitating iterative cycles of planning, implementation, testing, and revision in order to accomplish a single goal. This aligns with the first standard of the Common Core Standards for Mathematical Practice, "Make sense of problems and persevere in solving them," [11] and with the modern theory of grit. Grit is perseverance and passion for long-term goals as shown by working through challenges, failures, and adversity with consistent effort. Studies have shown that grit is a better indicator of achievement and success in life than intelligence [12]. Arts & Bots projects also align with objectives from the 2011 AP Computer Science: Principles, including "Learning Objective 1: The student can use computing tools and techniques to create artifacts," and "Learning Objective 3: The student can use computing tools and techniques for creative expression." [13] In addition to these learning objectives held in common across Arts & Bots projects, Arts & Bots also supports the learning goals of the specific discipline within which it is implemented. Below we give three such examples.

Poetry

In 2012, a small, suburban, public, junior-senior high school began implementing Arts & Bots in their seventh and eighth grade Language Arts classes (students age 12-14 years). Over the course of two years, 69 students participated in the project with 18 of these students participating in both years. Over five class days (roughly 14 contact hours), students worked in groups of three or four to analyze a poem and design a robot theater (Figure 1) which they would build and program to express their poem. Students recorded audio clips of themselves reading the poem and incorporated these clips into the programs they wrote. The project addressed a number of Pennsylvania's Academic Standards, including: 1.3.8.D analyze the effect of various literary devices (e.g., personification, simile, alliteration, symbolism, metaphor, hyperbole, imagery); and 1.1.8.A apply appropriate strategies to interpret and analyze author's purpose, using grade level text. Teacher interviews suggest that the robot building process helped students to better understand the poems; one student, while working on her theater of Edgar Allan Poe's "El Dorado" had the sudden realization that the poem was not just about the search for gold, but about the search for happiness.

History / English

A small, rural, public, K-8 school implemented an Arts & Bots project with its 37 seventh grade students (12-14 years old). The project was spread over the course of the school year (roughly 20 contact hours), incorporating units in history, English, science, and math. 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 (Figure 1) and programmed them to act out the biography. By implementing a robotic character, as opposed to a purely written assignment, students were required to form a detailed understanding of their historical figure since imitating the person required coherent insight into that person's personality, appearance, and actions. The project addressed a number of Pennsylvania's Academic Standards, including: 8.4.8.A compare the role groups and individuals played in the social, political, cultural, and economic development throughout world history; and 1.8.8.B conduct inquiry and research on self-selected or assigned topics, issues, or problems using a variety of appropriate media sources and strategies.

Human Anatomy

Over the last two years, a human anatomy class at a small, urban, all-girls, independent, preK-12 school was taught to a total 21 12th grade students (age 17-18) which incorporated an Arts & Bots project covering the musculoskeletal system. Previously, the course included a lab component where, as a class, students simulated muscles and ligament attachments by connecting artificial muscles to the classroom skeleton model. This project was replaced by an Arts & Bots project in which, over the course of five weeks (about 13 contact

hours), students worked in teams to construct anatomical models of the human arm using the Arts & Bots kits, red tights for muscles, rubber bands for tendons, and foam core board for bone (Figure 1). Servos, triggered by a sensor, controlled the movement of the elbow and wrist joints. The students were required to implement 10 major arm muscles and be able to emulate at least five motions of the elbow and wrist. The primary learning objective of the lesson was to give the students an opportunity to practice applying knowledge about the macroscopic features of bones, muscles, and tendons to create their robots. This experience allowed them to explore the interactions between bones, muscles, and the resulting movements by encouraging experimentation in imitating the functionality of a human arm. The project addressed a number of Pennsylvania's Academic Standards, including: 3.1.10.A8 investigate the spatial relationships of organisms' anatomical features using specimens, models, or computer programs; and 3.4.10.C1 apply the components of the technological design process.

Discussion & Future Works

The success of Arts & Bots stems from its ability to integrate with and support learning goals in any number of subject areas. In order to integrate with such a wide variety of subjects, a project must go beyond a one-size-fits all model and prepackaged curriculum. Educators must be empowered to use the technology as a tool, customizing its implementation for their own discipline. Professional development has to scaffold educators with the technical background needed to develop and teach the curriculum, as well as provide inspiration through proven successful examples. A powerful way to sharpen these skills is to provide educators with the authentic experience that their students will have in the classroom

Our future work, in progress, is focused on the analysis of student data, collected during several of the classroom implementations, to determine the efficacy of Arts & Bots on student technology fluency. In addition, we plan to develop evaluation tools and collect data specifically related to the impact of Arts & Bots on disciplinary learning (e.g., how does robotics support understanding poetry). Work will also continue towards further refinement of the hardware and software components of Arts & Bots with an emphasis on easing classroom implementation.

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