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Utilizing Engineering to Teach Non-Technical Disciplines: Case Studies of Robotics within Middle School English and Health Classes

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***Abstract*— When engineering and computing activities are solely electives, extra curriculars, or informal learning activities, student participation is limited by self-selection. By integrating technological projects into required coursework, all students gain exposure. The Arts & Bots Math and Science Partnership integrates creative robotics into middle school classes such as English and history as transdisciplinary, creative robotics projects. We discuss two case studies of such projects, describing how teachers developed projects through sequential implementations; and how project instruction focuses on developing student technological fluency, collaboration, and understanding of class content. One case study describes the integration of Arts & Bots into 7th and 8th grade English Language Arts in which students build robotic sculptures that represent a poem or scene in a play. The second case study describes a 7th grade Health and Physical Education project in which students build models of human joints and limbs in order to understand muscle pairs. We discuss differences, themes, and best practices for integration of creative robotics into non-technical classes through a comparison of projects implemented to date. The case studies are supplemented by data from student (N=195) and teacher (N=6) evaluations.**

Keywords—middle school; transdisciplinary; educational robotics; classroom learning environment; case study

I. Introduction

Involving K-12 students in STEM experiences and activities is a popular means for increasing the diversity and number of technologically fluent members of society. While many K-12 STEM interventions have been developed, as both in-school and extracurricular programs, they still frequently suffer from self-selection bias as elective activities. When engineering and computing activities are solely available as elective classes, extracurriculars, or in informal learning settings, the student engagement with these activities becomes limited by self-selection. Stereotypes about engineering and computing, lack of technology experience, or limited access to enrichment activities can all keep potentially talented students from discovering their affinity and strengths for learning and working with STEM related technology. Integrating robotics and other technological fluency projects into core coursework provides all students with exposure to hands-on, in-depth engineering and computing opportunities. The Arts & Bots Math and Science Partnership program achieves this integration through the use of creative robotics projects in middle school classes such as English Language Arts (ELA), health and physical education (HPE), and science.

II. Past Work

The Arts & Bots project began as an out of school project designed to increase both middle school girls' engagement with technology as well as technological fluency [1] [2] [3]. Technological fluency is defined as the ability to manipulate technology creatively and for one's own use as well as reformulate and synthesize new information [4] [5] [6]. Arts & Bots is a program in which students combine creativity-oriented craft materials with robotics components in order to build expressive robotic sculptures. The focus on creativity in Arts & Bots allows students to become creators through technology, as opposed to consumers of technology. Arts & Bots differs from other task-oriented, competition-based robotics interventions in that the focus is on expression, creativity, and communication. Despite this ideological shift, as an extracurricular program, Arts & Bots still suffered from self-selection bias. Even with strong efforts to recruit broadly, most girls participating in the project had existing interests in robotics and technology.

In order to address this selection bias, we worked cooperatively with teachers to adapt the project to meaningfully support non-technical content areas through in-school programs [7]. By non-technical content areas, we mean all subjects of K-12 classes except for engineering, technology education, and computer science. As Arts & Bots was refined, increasing students' technological fluency continued to be a goal of the in-school program. We also expanded our focus to support meaningful learning goals relevant to the non-technical course curriculum. During our in-school pilot studies (2010 to 2013), we found that students participating in the pilot program had gains in robotics learning, improved confidence with

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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 [8].

III. Current Work

The work presented in this paper builds upon our in-school pilot program. Through the Arts & Bots project, teachers of all disciplines can receive training on the construction and programming of creative robotic devices, the development of project curriculum, and the identification of STEM talents and affinities in students. These non-technical teachers develop project curricula with the intent of using robotics as a vehicle to intertwine content learning goals with ideas from engineering design and computer science. For example, students design and build robots to illustrate the features of a famous ancient structure, or share the life story of a scientist. During the projects, students use the Hummingbird Robotics Kit [9] combined with craft or recycled materials to construct their robots. They program the robots using a visual programming language through which they first create “expressions”, saved configurations of outputs, and then combine these expressions into “sequences”, much like storyboard frames are combined. The programming language is described in more detail in [10].

In this paper, we provide two case studies of such projects; describe how the projects were refined and developed by teachers through sequential implementations; and describe how the project instruction targets developing student technological fluency, collaboration, and understanding of class content. One case study presented is the integration of Arts & Bots into English Language Arts (ELA) for seventh and eighth grade students in which students build robotic sculptures that represent a poem or scene in a play. The second case study presented is from seventh grade Health and Physical Education (HPE) classes in which students build models of human joints and limbs in order to study complementary muscle motion. These two case studies examine projects which integrate disciplinary content and robotics, where the robotics project: (a) is linked to a disciplinary ‘big idea’; (b) is designed to support the development of key concepts; (c) and includes classroom activities, materials and evaluation which reinforce learning goals in the integrated discipline. This style of integration is contrasted with two other styles of robotics project integration, described in [11]. We document how the projects have developed over three years, beginning in 2013, through feedback from students and teachers. Finally, we discuss differences, themes, and best practices for the integration of creative robotics into non-technical core classes through a comparison of the two case studies, consisting of thirteen class projects developed and implemented as part of this project thus far.

IV. Development of Case Studies

Both case studies took place at a small, public suburban junior-senior high school located outside of Pittsburgh, which serves approximately 460 students in grades 7 through 12 (about 80 students per grade level). We collected data through a variety of methods, including classroom observations, teacher interviews and surveys, teacher logs and calendars of implementation, and student surveys and design portfolios. The analysis presented in this paper focuses on the data sources described in detail below and is specifically focused on student and teacher experiences in the ELA and HPE classes described in this case study. Our analysis of other sources is still in progress. Teacher interviews were conducted by an external evaluator before implementation and during or after implementations. Student survey data was collected through pre-surveys distributed at the beginning of each implementation, “Exit Tickets” completed by each student at the conclusion of each class period, and post-surveys distributed at the end of each implementation. When completing “Exit Tickets,” students indicated their activities for the day choosing from 7 categories: The Class Topic; Designing and Planning; Building or Working with the Hummingbird, Motors, LEDs, or Sensors; Art or Decoration; Programming; Final Presentation or Demonstration; and Other. We analyzed Case-Study-relevant Exit Tickets (N = 1,415) for trends in activity distribution, attendance percentage, and implementation activity flow.

V. Case Study: English Language Arts

Middle school students are expected to develop skills in reading, analysis, and synthesis of different styles of written communications, such as poetry and plays using figurative language and symbolic imagery. Middle school students encountering poetry or Shakespeare for the first time need to critically read passages numerous times to truly understand and decompose their meaning. However, the traditional activity of reading and analyzing passages from a text can prove tedious to students who are reluctant to spend additional time reading a single passage. The creative use of digital technology and project-based learning activities is a logical choice for motivating students to engage with text for longer periods. Project-based learning has been linked to increases in student motivation, attitudes towards learning, and teamwork skills among other benefits [12][13].

The Arts & Bots robotics project, presented in this case study, is designed to support ELA learning objectives aligned with literary analysis. The principle goal of the project is for the students to carefully decompose the literary elements of an assigned text, either a poem in seventh grade or a passage from Romeo and Juliet in eighth grade. Students analyze, interpret, and design a sculptural, robotic representation of a poem (Fig. 1). The final robotics project deliverable serves as a means of evaluating student knowledge and skills while the process supports meaningful engagement with the ELA content. For example, a group of seventh grade boys working with Walt Whitman’s A Noiseless Patient Spider initially referred to a dictionary numerous times while reading, but were able to relate in the final presentation that the filament from the spider reminded them of feelings leaving a soul. This case study is a record of the development of the ELA robotics project between 2011 and 2016. The case incorporates data from the seven most recent projects spanning three academic years and dating between 2014 and 2016. These projects were completed by six teachers, 51 seventh grade students, and 144 eighth grade students.

A. Project description

This case study examines the development of a project in which seventh grade and eighth grade students worked in collaborative groups to interpret literature passages and create representations. Poems for the seventh grade classes are chosen by the teacher based on the use of the figurative language and symbolism that best represents the seventh grade curricular goals. After reading Shakespeare's Romeo and Juliet, eighth grade students are assigned a monologue, sonnet, or soliloquy to dissect and explore the meaning and significance of symbolism and word choice. The students then communicate their analysis by creating a visual representation of the text with the use of Hummingbird Robotics Kits and craft materials with more rigorous requirements than the first seventh grade implementation.

B. Class schedule

The timeline of this project involves 5 days of block scheduling (10 class periods). On the first day, students take a pre-survey examining their knowledge of building and programming as well as attitudes towards technology and technical careers. Then, they are assigned into a group of 3, provided with a copy of their literary work, and a planning document. The planning document requires students to dissect the work, draft a visual plan of their project, contemplate possible programming expressions, delegate tasks, and reflect on the limitations for meeting the project deadline. Students must complete and get their planning document approved prior to starting the building/programming process. On the second day, the priority is for students to adhere to the tasks that were delegated. Students create audio recordings using Audacity [14]; another member begins construction; while the third member begins creating expressions. The third day's goals are to transfer all of the audio files to the visual programming software, continue construction, and further the programming sequence. The fourth day is dedicated to finalizing the build and programming sequence. The fifth day is to tweak, refine and present final projects to peers. This day is also used as a reflection on individual contributions and team dynamics through a post-reflection activity. Note that if the survey time was not included, the class implementation would consist of 8 class periods or 4 days.

Student Exit Ticket responses support that students experiences roughly follow the class schedule as planned by the teacher. These Exit Tickets allow us to examine how teams delegate project tasks and how the experiences of individuals differ. For the seven English Language Arts and Advanced English Language Arts implementations, 49.2% of students that reported "The Class Topic" as their task for the day, reported so on Day 1 of the implementation, with the percentages decreasing in the later days of the implementation. 35.1% of "Designing and Planning" task reports occurred on Day 1 of the implementations. Day 3, the middle of the implementations, had the highest percentage of the task reports for "Art or Decoration" with 31.7%. Similarly, 33.6% of all "Programming" task reports occurred on Day 3 of the implementations. "Building or Working with Robot Parts" followed shortly after, with 52.4% of reports occurring on Day 4 of the implementations.

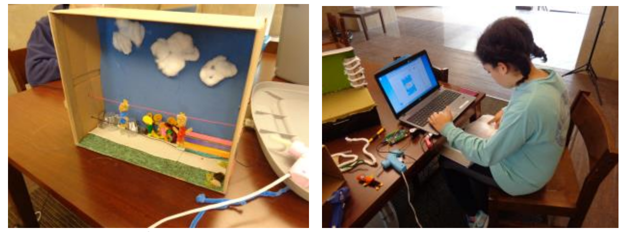

Fig. 1: (From left to right) In progress project, student working on expressions

C. Project assessment

The students' language arts skills are assessed through all phases of the project using a rubric developed by the ELA teachers. The assessment rubric possesses seven primary areas. First, the planning document is assessed for writing conventions as well as selection comprehension and literary analysis. Second, the recording of the literary work with Audacity is reviewed for correct pronunciation, expression, meter, and adherence to conventions such as commas, periods, and dashes. Third, in all collaborative activities during the project, formative assessment of the students' ability to clearly express their ideas is captured in the teamwork portion of the rubric (ELA Standard - CC.1.5.8.A). Fourth, the programing work for the project is graded for how well the robotic elements are paired to specific words or phrases. For example, one group placed circular disks on two motors and used alternating backward and forward motion to accentuate Mecurtio and Tybalt's actions during the famous Act III fight scene in Romeo and Juliet. Fifth, the rubric indicates a minimum number of robotic parts as well as the expectation that a sensor is used for starting "the show." Sixth, the "arts" in this project must reflect the symbolism of the literature and is graded accordingly. For example, the famous balcony scene in which Romeo professes his love for Juliet with great celestial imagery is perfect for pushing blinking yellow LEDS through a dark background to represent twinkling stars. Seventh, to meet the sharing requirement of the rubric, students must give a final presentation in which they provide a summary and analysis of their group's selection, explain how their robotics and art are representative of specific text, and reflect on their group's collaboration skills.

D. Curriculum development and refinement

Throughout the development of the projects, ELA teachers collaboratively taught the class with a gifted enrichment educator. In the early development of the projects, the gifted enrichment educator and ELA teacher performed classroom technology and ELA content instruction, respectively. As the ELA teachers gained experience through co-teaching, they began to take an increasing role in the technology instruction, while the gifted educator moved to more of a support role.

In the five school years since the initial Arts & Bots implementation, the teachers have experimented with the placement of units ranging on a continuum of skills and requirements. As teacher confidence and familiarity with the Hummingbird Robotics Kit increased, they were motivated and able to correspondingly increase the difficulty of the project for their students. During early ELA implementations in both 7th and 8th grade, a significant amount of unit time was devoted to learning the software, understanding the potential of LEDs, servos, and motors, and troubleshooting technology glitches presented by working in the locked-down computing environment of a school district. These classes have grown into a series of two independent projects of increasing difficulty with the seventh grade classes focusing on general poetry while the eighth grade classes focus on more difficult Shakespearian content, including more challenging vocabulary and unfamiliar sentence structure.

In order to prepare the seventh grade students for the higher expectations and difficulty of the project, an introductory unit was added to sixth grade technology classes in which the students used a pre-constructed robot to learn the skills necessary to manipulate the visual programming software to control the robotic parts. The inclusion of this introductory unit during the fourth year of Arts & Bots implementations has changed how 7th and 8th grade teachers use instructional time in the ELA Arts & Bots unit. Teachers are able to spend less instructional time teaching programming and robotics, and more time on cultivating STEM talent in their content areas.

Additionally, teachers have instituted a rigorous planning process in which each collaborative team must complete an eight page planning document before gaining access to building supplies and Hummingbird kits. Teachers utilize this planning document simultaneously to combine and address both the Pennsylvania technology standard 3.4.8.C2 for exploring the design process and English Language Arts standard CC.1.3.8.C for the analysis of dialogue. In this case study, the teachers created a planning document in which the students provide a line of text, explain the meaning of the text in their own words, plan for art to symbolize or illuminate the text, and finally incorporate robotics into the symbolization. This process keeps the planning rooted in the core content realm and has resulted in projects that demonstrate a higher degree of attention to detail across all aspects of the project. Because core-content teachers have such vast curricula to cover each year, optimizing project tasks is absolutely necessary and has contributed to the success of the Arts & Bots program.

The 8th grade teachers have also observed skill benefits now that students come into the Shakespearean project with two years of previous Arts & Bots experiences using both the software and robotic kits. Though the projects differ in requirements and final product, the familiarization with the Arts & Bots kits resulted in a more fluid transition into the curriculum with students willing to take more risks in engineering and design.

The Arts & Bots projects are an opportunity for staff and students alike to continually improve the collective understanding of the presence of robots in the modern world. In the initial implementation years, it was rare that 8th grade student groups had the understanding to include a sensor as a start to the robotic diorama. While in year five, 25% of the 7th grade groups in every social studies project were able to follow instructions for a "Ready Set Go" feature that included the nesting of sensor structures in the visual programmer software. This example alone illustrates the depth of impact the Arts & Bots program has had on student learning and outcomes.

VI. Case Study: Health and Physical Education

Identifying and cultivating STEM talent in middle school students is a skill set that is rarely, if at all, mastered or explored in a non-technical setting such as Health and Physical Education (HPE) class. However, there is a natural relationship between physical education, science, and math. In 2013, after being inspired by a 12th grade anatomy project presented at an Arts & Bots workshop, the HPE department in conjunction with the Arts & Bots program devised a project that would utilize Hummingbird robotics kits to teach middle school students the principles of biomechanics, specifically complementary muscle movements. Using robotics kits to facilitate learning is a far departure from typical teaching methods in HPE courses, and certainly fits the notion of teaching STEM skills in a non-technical setting. Knowing that students are self-selecting out of STEM classes by middle-school, it has been a clear goal for the two HPE teachers involved to thoughtfully design a project that allowed learning biomechanics to take center stage, while more subtly allowing students to be immersed in a culture that promotes the deeper values of STEM learning. Throughout the past three years, the project has grown through several iterations, while equally deepening the depth of learning taking place in the classroom and creating a positive culture around STEM.

The major objective of the "Robotic Joint" project has been to have students create biomechanically correct and working joints using the Hummingbird robotics kits and 95% recycled materials. Biomechanics has typically been a rather dry and unexciting topic to teach to middle school students. At best, to understand this concept students in the past have been able to view working diagrams, watch videos, or try to feel their own muscles working in complementary motions. However, with the infusion of STEM into the non-technical setting of HPE class, students are now able to create in an engaging way a product that demonstrates a much deeper understanding of complimentary motion.

This case study is a record of six HPE robotics projects completed between 2014 and 2016. These projects were completed over 3 school years by 2 teachers and 89 seventh grade students. Note that student survey and exit ticket data is only analyzed for five classes due to ongoing data processing at the time of writing.

A. *Project description*

The students work in small teams of 2-3 members to research, prototype, program, build and present their working joint to the class. The teams are allowed to choose 1 of 3 joints to recreate (elbow, knee, or shoulder), which demonstrate varying degrees of difficulty and understanding. Each team researches their chosen joint, documenting the critical bones and muscles involved in the joint's motion. To guide students through the engineering design process, students must draw, get feedback on, and receive approval of a schematic plan of their joint before they are allowed to begin physically building. The robots are constructed with a focus on biomechanical accuracy, with specific materials and robotic components standing in for important bones and muscles. For example, a student could use a recycled cardboard tube to represent the femur in a knee model. Students are expected to label the bones and muscles in their working models. Once the project is completed, students present their models to their peers.

B. Class schedule

The students are given approximately 10 class periods (45 minutes/class), 2 of which are used to complete research surveys. The remaining 8 are used to research, design, build, and present the entire project. During the first class period, students are introduced to the project parameters and a brief explanation of biomechanics. On the second and third days, students research a specific joint and begin drawing a schematic of their project. Once students have their planning document approved, the remaining class periods are dedicated to building, programming, and presentation preparation. On the final day of the project, all of the teams present and demo their robots to the entire class.

Student Exit Ticket responses support that task distribution across the implementation roughly follows the schedule as laid out by the teachers. These Exit Tickets allow us to examine how teams delegate project tasks and how the experiences of individuals differ. For the six Health implementations, 22.2% of students that reported “The Class Topic” as their task for the day, reported so on Day 2 of the implementation, with the percentages decreasing in the later days of the implementation. 19.9% and 16.2% of “Designing and Planning” task reports occurred on Days 2 and 3 of the implementations, respectively. Days 4, 5, 6, and 7 had the highest percentage of the task reports for “Art or Decoration” with 13.3%, 16.0%, 14.7%, and 19.5%, respectively. 17.8% of all “Programming” task reports occurred on Day 7 of the implementations. Similarly, 17.3% of “Building or Working with Robot Parts” task reports occurred on Day 7 of the implementations.

C. Project assessment

Upon completion of the project, the students are assessed in four key categories of learning using a rubric developed by the HPE teachers. First, students are assessed on their understanding of biomechanical principles. The finished robot must correctly demonstrate complementary motion by using the robotic mechanisms in a way that mimics how the body muscles would work. For example, using two motors placed correctly to pull the bicep and tricep muscles around the elbow joint in an antagonistic way would demonstrate learning in this area. Placing one servo at the elbow, which moves the forearm up and down, would not demonstrate learning in this area. The second area of assessment is programming. In this category, the students must demonstrate a complexity of programming that allows for accurate movement of their joint. The third category is the “Bots” category, which consists of successfully building a working joint free of catastrophic failures that also meets a minimum requirement of robotics parts in use. The fourth and final area of assessment is the “Arts” category. In this assessment area students demonstrate that they can empathize with and communicate an idea through their design process. Successful projects in this category often have well polished final projects with a clear purpose communicated. In addition to this, using these 4 categories as a framework for the projects allows the students to take non-linear paths to learning the content of biomechanics. It is interesting to see how the same ideas can be communicated in an unlimited number of ways. Ultimately, through this assessment method, we can see how students have either deepened their mastery of biomechanics and STEM or can be identified as being in need of more attention and talent cultivation.

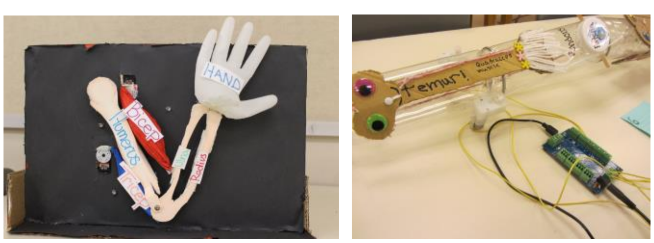

Fig. 2: (From left to right) Final elbow model; Final knee model

D. Curriculum development and refinement

To understand more fully how this project has changed over the past 3 years, it is important to understand the teaching dynamic for this specific project. In this instance, this project is co-taught between a HPE teacher that is extremely comfortable with technology integration and another HPE teacher that is at the beginning stages of implementing technology. Because of this teaching dynamic the first year’s ideation and implementation was unintentionally focused around the novelty of using technology to make a moving arm. For the project, the teachers were more concerned about learning how to manage a classroom using Hummingbird Kits and making something that “just worked” instead of really honing in on the concept of biomechanics.

As the teachers began to master the skills of managing the new project, the less tech-comfortable teacher was able to take over more responsibilities around solving technical issues. As this shift occurred, the more tech-comfortable teacher was able to explore ways in which to focus the project more around learning biomechanics. For example, in the second year of the project, a much stronger emphasis was placed around getting students to place motors and servos in places that more truly mimicked the origin and insertion of muscles. This was the year that we began to really understand the impact that implementing Arts & Bots could have on highlighting our content area. Additionally, we began to see much higher quality projects emerge that truly communicated the concept of complementary biomechanical motion.

As we have now progressed into our third year of the project, the understanding of the technology for the teachers has become much less important, and much more time is spent around improving the teaching strategies that accompany the project. For example, a planning schematic that must be approved before building has become a staple of the project. We have learned the importance of planning in relation to our builds to save time, energy and unnecessary failure and ultimately produce better projects. We equate the pre-building planning to be very similar to pre-writing strategies for language arts classes. Although students will need to deviate from their plan, they are not haphazardly building things that will not work.

This project has had an equally dramatic impact in the pedagogy of the HPE teachers involved. First, over the past three years through the self-reflection this research project demands, the teachers have consistently revised the project to better align the real learning taking place. For example, in the first implementation of the Robotic Joint project, final projects were far from demonstrating biomechanical principles. Often times motors were haphazardly placed or projects partially completed. Now, the teachers have learned how to encourage the students to look at the technology as the raw material for building and manipulate it to fit the needs of the project.

Overall, it has been plain to see that as our skills and comfort levels with the technology improved, our ability to focus on pedagogy was able to become much more of the focus. Other teachers that will implement Arts & Bots will surely experience similar learning pathways, and it is important to note this when considering how to provide meaningful professional development to educators about Arts & Bots.

VII. Case Study Discussion

The two case studies above are constructed of qualitative data collected through teacher interviews, logs, and surveys, along with classroom observations and student Exit Ticket surveys. These data allow us to provide cases describing development and implementation of projects and permit the synthesis of conclusions about the differences, themes, and best practices documented in the ELA and HPE projects.

A. Differences

The two case studies presented here demonstrate both structural and contextual differences. While both classes spent a total of 10 class periods on the project, the ELA classes capitalize on block scheduling to provide longer work periods than the HPE classes, which are limited to single-period class sessions. Since teachers have multiple classes in their rooms each day, it is important that students take out their projects at the beginning of each class and put away their work materials at the end of each class. For elaborate construction projects such as these, this results in 5 to 10 minutes of each class being spent off-task. In the ELA classes, the students benefit from double block periods, which permit them to tear-down and set-up their project half as often as the HPE classes. At the end of a ten-class period project, the HPE students spend an additional 25 to 50 minutes of class time on set-up and clean-up compared to the ELA classes.

By its complex nature, Arts & Bots has numerous aspects of the process, project, and materials that can play complementary roles, depending on the needs of the disciplinary content. The two cases present two different projects which emphasize different aspects of the robotics project. The ELA projects emphasize literary symbolism and comprehension. Subsequently, the robotics aspects of the projects and rubric focus on art, design, and communication. The HPE project emphasizes biomechanical aspects of the human joints, bones, and muscles. Therefore, the robotics aspects of the project and rubric focus on mechanical design and physical construction.

B. Themes

Having observed Arts & Bots implementations 6 times in HPE classes and 7 times in ELA classes, we have identified a number themes shared across both case studies. While the ELA and HPE projects emphasize different aspects of the design space, they both use the integration of robotics to help improve the learning process for students, increasing engagement and depth of conceptual understanding. Though the technological integration is integral to the learning outcome, the technology goals are treated as secondary. We observed that students treat robotics components as another material, giving it equal consideration as they do recycled and craft materials.

Teachers in both case studies gained confidence with the technology over time, allowing them to reduce the emphasis on the technology itself and achieve a deeper integration with their class content. As teachers developed a deeper understanding of the technology they are able to help students do more complex activities.

Finally both projects allow students to be exposed and engaged in coding and programming in a setting that is comfortable for exploration. Through the construction of a tangible robot, fabricating parts, and wiring electronics, every student has the opportunity to physically and mentally engage in the engineering design process. Student Exit Ticket responses suggest that while the freedom to differentiate tasks among teammates leads to some self selection, the majority of students gain hands-on exposure to engineering and computing. Of the 284 students completing Exit Tickets only 6.7% of students never list “Building or Working with Robot Parts” or “Programming” as a task they worked on.

C. Best Practices

From the two case studies, we synthesized a list of three recommended Best Practices for implementing integrated robotics projects:

1. Planning Materials - Both classes use planning materials and scaffolding activities that help their students to better connect their projects to the ELA and HPE subject content through explicit designing and planning. In engineering and design projects it is especially important to scaffold the design process for novices who are inclined to start building without sufficient planning.
2. Practice while Co-Teaching - In both cases, the teachers develop the project and their own skills through co-teaching and in-class practice across multiple years. By sharing responsibilities in the co-taught classroom, teachers practice running Arts & Bots projects and gain familiarity with the robotics technologies, while benefitting from the experience and support of a mentor or peer.
3. Rubric Design - During the development of both projects, teachers developed evaluation rubrics tailored to their content areas and emphasizing both content learning objectives and complementary technology learning

objectives. When the project is very complex, the rubric helps keep students from going too in-depth in any one area and stay on task to achieve the desired learning outcomes.

VIII. Preliminary Evaluation Method

We used student responses to short-answer survey questions to garner additional insight into the student experiences during the case study projects. In order to quantitatively analyze these qualitative responses, we first developed a coding scheme and then coded the responses. We reviewed a total of 1,370 open-ended responses from the student-completed post-surveys for coding (274 responses for each of five questions). When coding open-ended student responses, two raters coded 20% (N=275) of the response set in 86% agreement. The interrater reliability for the raters was found to be Cohen's Kappa = 0.762 ($p < 0.001$). Cohen's Kappa statistics for each individual question are given in Table 1. The raters assigned codes from a set of 58 universal codes across questions. In addition to this universal code set, question-specific codes were also available for assignment. In total, a rater could choose from 59 codes for "How did this experience change how you think about technology?", 67 codes for "Do you have any suggestions for improvements?", 61 codes for "Should other students have this experience? Why or why not?", and 58 codes for "What was the best thing you learned during this project?" and "Did you enjoy this project? Why or why not?". No limit was provided regarding the number of codes that could be assigned to each student response resulting in the total number of codes (N_C=394) being larger than the total number of student responses (N_R=274). When there was disagreement between raters, the raters discussed the open ended survey answers and agreed upon the specific codes to be assigned to each response.

IX. Preliminary Program Evaluation

In their short answer survey responses, students report technical learning, multidisciplinary learning, gain of appreciation for technology, teamwork experience, and experiential enjoyment as positive outcomes of participating in their Arts & Bots implementation.

Specifically in response to the question "Did you enjoy this project?" 78.9% of codes assigned are positive , and 19.8% of codes assigned are negative (NC=394). Responses assigned the code "Fun and Enjoyment (General or Technology)" indicate that students expressed either the anticipation or the reflection of liking aspects of the experience. This code was the most commonly assigned code for the question "Did you enjoy this project?", (29.9% of student responses were assigned this code from Nr=274 responses) and "Should other students have this experience?" (26.3% of responses). It was the 4th most commonly assigned code for the question "How did this experience change how you think about technology?" (11.3% of responses). Another noteworthy code assignment refers to the enjoyment of the multidisciplinary or creative nature of the project (10.6% of responses to "Did you enjoy this project?"). For example one 8th grade student stated, "... I also liked that I got to interpret literature through technology."

TABLE I. Interrater Reliability

Survey Question	Cohen's Kappa	p value
"How did this experience change how you think about technology?"	0.787	< 0.001
"What was the best thing you learned during this project?"	0.827	< 0.001
"Did you enjoy this project? Why or why not?"	0.651	< 0.001
"Do you have any suggestions for improvements?"	0.879	< 0.001
"Should other students have this expereince? Why or why not?"	0.642	< 0.001
Overall	0.762	< 0.001

Technical learning is also broadly reported by students ranking as the 1st, 2nd, or 3rd response to each of the four questions (see Table 2). This code indicates a response expressing any desire to learn about or an increased understanding of robots, technology, electronics, programming, or computers. Other learning is also frequently reported. Students say that the best thing they learned is an increased understanding of the class topic in 8.4% of responses to "What was the best thing that you learned during the project?". Students comment that they enjoyed learning without being specific as to what exactly they had learned in 5.5% of responses to the question "Did you enjoy this project?", and that others would learn something in 16.1% of responses to the question "Should other students have this experience?".

Positive teamwork experiences are the 2nd most frequent code for "What was the best thing that you learned during the project?" (23.4% of responses) and "Did you enjoy this project?" (19.7% of responses). For example one 8th grade student stated, "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.". Students also stated that others would learn teamwork from the project as a reason that other students should have this experience (10.2% of responses). It is worth noting that negative teamwork experiences are cited in 7.7% of responses to "Did you enjoy this project?" indicating that while many students enjoy the teamwork or find value in practicing their teamwork skills, for some students poor experiences with their team limit their enjoyment of the project.

Arts & Bots changes student perceptions of technology for many students. While some report no change (20.4% of responses), several interesting changes are reported in response to the question "How did this experience change how you think about technology?". An 8th grade student stated, "it is a lot more difficult then most people think there is a lot more stuff going into this than what's coming out of it.". This student recognized the amount of hard work and dedication one must apply in order to work with technology successfully. This is one example of the 19.0% of student responses which express that this experience encouraged them to appreciate further the complexity of technology or recognize the difficulty involved in designing new technology. It is not always possible to tell from student responses if they feel positively or negatively

TABLE II. PERCENTAGE OF STUDENT RESPONSES ASSIGNED EACH CODE BY QUESTION

Percent Assigned[a]	Code
"Did you enjoy this project? Why or why not?"	
29.0%	Fun and Enjoyment (General or Technology)
19.7%	Teamwork
12.4%	Technical Learning
10.6%	Multidisciplinary
8.0%	Enjoy Building
7.7%	Negative Teamwork
6.9%	New, Novelty, Different
5.5%	Vague Learning
"How did this experience change how you think about technology?"	
20.4%	No Changed Reported
19.0%	Appreciation for the Complexity
16.1%	Technical Learning
11.3%	Fun and Enjoyment (General or Technology)
9.5%	Appreciation for the Broader Applicability of Technology
7.3%	Easy or Less Challenging
"Should other students have this experience? Why or why not?"	
26.3%	Fun or Enjoyment (General or Technology)
23.4%	Technical Learning
16.1%	Vague Learning
12.4%	My Career
10.2%	Teamwork
5.8%	Vague Positive
5.1%	Students should be allowed to choose
"What was the best thing you learned?"	
45.6%	Technical Learning
23.4%	Teamwork
8.4%	Disciplinary Learning

[a.] Codes representing less than 5% of responses are not shown.

about the difficulty, and so these responses were coded into a single category. As a counterpoint, 7.3% of responses express the view that the project or technology is easier than they had expected. Additionally, two separate 8th grade students describe their new perspective on technology through amazement and wonder saying, "It never ceased to amaze and inspire me." and "This experience changed how i think about technology because i got to learn a lot about robotics and technology that i did not already know, and it showed me that robotics and technology is pretty amazing.". These students are not alone. In fact, 9.5% of student responses express a further understanding for the broader applications of technology, meaning they actually learned about the uses of technology in the world. Taken together we interpret these results to mean that the experience helps ground student perspectives of robotics and engineering, allowing them to judge the challenges of engineering based on a real life experience rather than speculation.

Finally students feel that their Arts & Bots experiences are worthwhile for gaining experience which will be useful in their future or help students explore and discover interest in technical careers. A 7th grade student described why students should have this experience saying, "Yes because it really helps you see if you have a gift in this field.". This is a recurring sentiment. In response to, "Should other students have this experience? Why or why not?", 12.4% of student responses were coded as My Career. Overall students recommend Arts & Bots be offered to other students; 88.7% of codes assigned are positive (n=355), 5.4% of codes assigned are mixed, and only 4.8% of codes assigned are negative.

X. CONCLUSION

We present two case studies which describe the development and features of two frameworks for integrated robotics projects. There are several key elements discussed in each case study including: introduction to the project and learning objectives, description of the project, details on the project schedule, information about how the project is assessed, and final a discussion of the curriculum's development. We found a number of notable differences, themes, and best practices by contrasting English Language Arts and Health and Physical Education project case studies.

Although the case studies both integrate Arts & Bots projects with course content, they demonstrate both structural and contextual differences. The longer length block-period classes allow students to spend more time on task during the project even though in-class time is approximately equal. With one case study focused on English Language Arts and the other on Health and Physical Education, the robotics emphasis of the projects varies from art and communication to engineering design respectively.

A number of themes are shared across both case studies. Both use integrated robotics to improve student learning, engagement, and understanding of class content. Over time, teachers gain confidence with technology such that technology becomes more deeply integrated with class content. Most students gain exposure to engineering and computer programming even though students are given freedom to delegate tasks among team members.

We present three Best Practices for integrated robotics projects: planning materials, practice while co-teaching, and rubric design. The successful integrated robotics projects implement an explicit planning activity in which students complete a planning document illustrating their robot design and connections to non-technical content. From the integrated robotics project case studies, we recommend that teachers be given time to hone their skills with new technical content and have the support of peers through co-teaching. We also recommend that integrated robotics projects include grading rubrics which balance technology requirements and disciplinary goals in order to focus student design processes and learning outcomes.

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