Creative Robotic Systems for Talent-Based Learning

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CREATIVE ROBOTIC SYSTEMS FOR TALENT-BASED LEARNING

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Abstract

In recent years, the U.S. educational system has fallen short in training the technology innovators of the future. To do so, we must give students the experience of designing and creating technological artifacts, rather than relegating students to the role of technology consumers. We also must provide educators with opportunities and professional development for identifying and supporting their students' talents. This is especially important for the identification of student talents in computational thinking or engineering design, where schools commonly lack educators well-versed in those domains.

Educational robotics systems are one possible method for providing educators and students with these opportunities. Our creative robotics program, Arts & Bots, combines craft materials with robotic construction and programming tasks. Arts & Bots is integrated with non-technical disciplines and encourages a wide variety of student talents surface. This thesis describes our process in developing Arts & Bots as a tool for talent-based learning. We define talent-based learning as leveraging understanding of a student's talent areas to encourage and motivate learning. We look at this process and the outcomes of two multi-year Arts & Bots studies: a three-year Arts & Bots Pioneers study, where we integrated Arts & Bots into non-technical classes; and the four-year Arts & Bots Math-Science Partnership, where we further refined Arts & Bots as a tool for talent identification.

This thesis outlines our development of a teacher training model and case studies of two teacher-designed, Arts & Bots classroom projects. We present a taxonomy for novice-built robots along with other tools that support the identification of engineering design and computational thinking talent by non-technical teachers. Finally, we describe our development of a suite of evaluation tools for assessing the outcomes of the Arts & Bots program along with our findings from that evaluation.

For my parents, Bill and Sue Cross

Acknowledgments

I am forever grateful to have had the opportunity to work at the CREATE Lab with my advisor, Illah Nourbakhsh. Thank you, Illah for your advice, patience, and encouragement during my studies. Thank you for showing me again and again how to combine passion and compassion with scholarship. I could not have hoped to find a better mentor or role model. I am also thankful to the other members of my committee — Jack Mostow, Mitch Resnick, and Aaron Steinfeld. Thank you for taking the time to guide and encourage my work, and providing me with your interdisciplinary insight.

I first learned about the Robotics Institute at Carnegie Mellon while reading a book about robots, *Robo Sapiens*, in middle school. The Robotics Institute is a one-of-a-kind place. Thank you to the faculty, staff, and students of the Robotics Institute who provided me with never-ending opportunities to learn and flourish during my time here. The Program in Interdisciplinary Education Research (PIER) at Carnegie Mellon has made possible the interdisciplinary nature of my studies, and this dissertation. Through PIER's funding and scholarly community, I learned more about instructional methods, education systems, and learning science than I could have anticipated. Thank you to the students, staff, and faculty of PIER — David Klahr, Sharon Carver, and so many others — who helped induct this engineer into the world of education through their enlightening discussions and thoughtful critiques.

None of this work would have been possible without the consistent guidance and efforts of Emily Hamner and Lauren Zito, who form the backbone of the Arts & Bots research team. Thank you, Emily, for being my sounding board over many years, and for all of your heroic efforts that made Arts & Bots successful. Your vision and passion are what made Arts & Bots what it is today. You are the best coauthor, mentor, and friend that I could have hoped to find. Thank you, Lauren, for enabling Arts & Bots to keep growing and running smoothly. I am incredibly grateful for all of your persistent effort, feedback, and encouragement, which significantly improved this dissertation.

I am so fortunate to work with the many members of the CREATE Lab who helped make Arts & Bots and my entire graduate experience a success. Thanks, all, for your many words of advice and support over the years. Beyond the CREATE Lab, Arts & Bots has grown through the efforts of many other organizations and partners. I would like to thank all of my wonderful collaborators and colleagues: Chris Bartley, Debra Bernstein, Harold Blanco, Michael Cassidy, Beatrice Dias, Lourdes Karas, Tom Lauwers, Karen Mutch-Jones, Clara Phillips, Carrie-Meghan Quick-Blanco, Cathy Walker, Karen Widmaier, Debbie Workman, Dror Yaron, and others. I am also grateful to the teachers, administrators, and students who have participated in Arts & Bots research over the years. Thank you, Anna von Reden, for helping me to copy-edit this dissertation, and to communicate with greater clarity.

We say that: "friends are the family that you choose." My Pittsburgh family — Andreya, Anna, Emily, Ilari, Jeff, Mike, and others — immensely improved my time in Pittsburgh. Thank you, all, for all the laughs, encouraging words, and occasional distractions. Your friendships are the perfect counter to the stresses of this dissertation.

My final and deepest thanks go to my parents, Bill and Sue Cross. I am forever grateful for the support that they have given me every day on my journey. They have constantly encouraged and inspired me to pursue my dreams — all the while challenging me to grow into a person with the abilities to achieve them. Thank you, mom and dad, for giving me a childhood where I had the freedom to bite off more than I could chew, and make mistakes. Thank you for the late nights spent encouraging me to do my best no matter what. This book is dedicated to you.

Contents

1

Introduction

In recent years, the U.S. educational system has fallen short in training the technology innovators of the future.[1] It is critical that schools and other education environments are able to support students in becoming the innovators of tomorrow. To do so, students must be given opportunities to develop and grow their creativity and talents for solving the technological, societal and environmental challenges of the future. Students need to gain experiences as designers and creators of technological artifacts, rather than being relegated to the role of technology consumers. It is important to chart a course for technological fluency for students, an idea defined and espoused by our prior research, among many others.[2]

[1] National Academy of Sciences, National Academy of Engineering, and Institute of Medicine. *Rising Above the Gathering Storm, Revisited: Rapidly Approaching Category 5*. The National Academies Press, Washington, DC, 2010; and National Science Board. *Preparing the next generation of stem innovators: Identifying and developing our nation's human capital*. National Science Foundation, Arlington, VA, 2010

[2] Debra Lynn Bernstein. *Developing Technological Fluency through Creative Robotics*. PhD thesis, University of Pittsburgh, 2010; Teresa M Amabile. *Creativity in context: Update to the social psychology of creativity*. Westview Press, 1996; Eva L. Baker and Harold F. O'Neil Jr. Technological fluency: Needed skills for the future. In Harold F. O'Neil Jr. and Ray S. Perez, editors, *Technology applications in education: A learning view*, pages 245–265. Routledge, 2003; and Mitchel Resnick. Closing the fluency gap. *Communications of the ACM*, 44(3):144–145, 2001

Student technological fluency is developed through activities where students are given freedom while creating solutions with technology. We believe that creating with technology is the key to enabling long-term engagement with STEM disciplines; creative flexibility drives intellectual curiosity and creative problem-solving, key lifelong skills necessary for STEM innovation.[3] Further, it is also crucial that students are challenged and supported during these activities in ways that cultivate their individual talents and interests to their maximum potential.

[3] Mihaly Csikszentmihalyi. *Creativity: Flow and the Psychology of Discovery and Invention*. Harper Collins, 1996; and National Science Board. *Preparing the next generation of stem innovators: Identifying and developing our nation's human capital*. National Science Foundation, Arlington, VA, 2010

For many children, technological fluency-supporting opportunities are provided to them through extracurricular experiences, either at home, in out-of-school programs, or through informal education environments. Robotics activities are extremely popular[4] vehicles for this type of activity, providing students with engaging real-world tasks and exposing them to a wide variety of experiences including: mechanical and electrical engineering, project management, teamwork, visual design, and problem solving. During these activities, students are able to practice skills and build confidence in their own talents, while educators are able to observe the process and provide appropriate support for student growth.

Unfortunately, these experiences are not accessible by all students. Some families lack the resources to provide the required time or materials at home, and/or cannot provide transportation to out-of-school programs. Other students live in geographic areas where these types of out-of-school programs or extracurricular activities are not available. Even when technology activities are available to students, they are frequently offered as elective programs where enrollment suffers from student self-selection. These activities thus fail to engage students who have little interest traditional technology programs or lack the confidence to participate in technological competitions (the predominant format of K-12 robotics activities).

The work presented herein includes the development process, implementation and evaluation results of a robotics program, Arts & Bots, aimed at providing a more diverse population of students with creative technology experiences. It achieves this through integration with required non-technical disciplines, and provides teachers of these disciplines with the experience and language they need to support student talents beyond their primary field. We believe that Arts & Bots serves not as a substitute for traditional technology electives and extracurricular activities, but as a complementary entry-point for involving many students in technological fluency development.

Technological fluency can be defined as the ability to manipulate technology creatively and for one's own use. In addition to creative expression, the National Research Council [1999] describes those fluent with technology as able to reformulate knowledge and synthesize new information.

National Research Council. *Being Fluent with Information Technology*. The National Academies Press, Washington, DC, 1999

Talent is defined by Gagné [2004] as "the outstanding mastery of systematically developed abilities (or skills) and knowledge in at least one field of human activity to a degree that places an individual at least among the top 10 percent of age peers who are or have been active in that field or fields." This is distinguished from **giftedness** which is "the possession and use of untrained and spontaneously expressed natural abilities (called outstanding aptitudes or gifts), in at least one ability domain, to a degree that places an individual at least among the top 10 percent of age peers." That is to say, where giftedness is a closely related to exceptional natural ability, talent is more about exceptional performance which can be developed with practice.

Françoys Gagné. Transforming gifts into talents: the DMGT as a developmental theory. *High ability studies*, 15(2): 119–147, 2004

Creativity is defined by Plucker et al. [2004] as the "interaction among aptitude, process, and environment by which an individual or group produces a perceptible product that is both novel and useful as defined within a social context."

Jonathan A Plucker, Ronald A Beghetto, and Gayle T Dow. Why isn't creativity more important to educational psychologists? potentials, pitfalls, and future directions in creativity research. *Educational psychologist*, 39(2): 83–96, 2004

[4] Some well known examples, include products such as LEGO MINDSTORMS, VEX Robotics, Bee-Bot, Sphero and Cubelets, as well as programs such as FIRST and BotBall.

We base the suitability of the Arts & Bots program for accomplishing this is based on two primary claims:

Inclusiveness We hypothesize creative technology programs in core required classes will eliminate student self-selection out of technology and engineering activities, casting a wider net for identifying and empowering all students with latent potential.

Empowerment We hypothesize technology tools that attract multiple talents will help students self-identify as individuals with the creative problem-solving capabilities needed to become future creators and innovators in STEM disciplines.

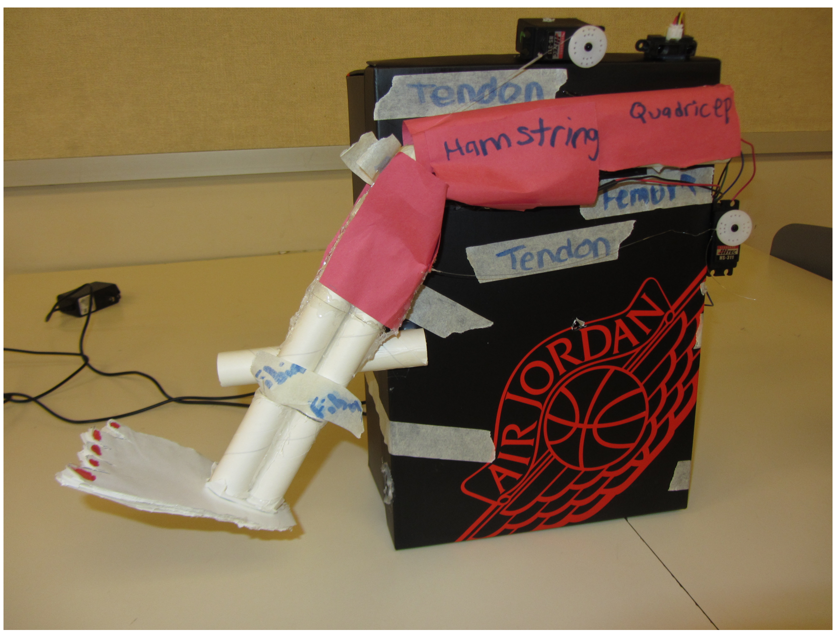

Figure 1.1: A student-built robot, from a seventh grade health class, modeling a knee musculoskeletal structure. The knee is programmed to extend and bend due to tension applied to strings attached to servo motors when something triggers the IR distance sensor (top right corner).

Arts & Bots

When it first began, the primary goal of the Arts & Bots program, developed by the Carnegie Mellon CREATE Lab, was to increase technological fluency of middle school-aged students. It sought to appeal to a broader group of students, who may have been uninterested or intimidated by existing robotics activities. Educational robotics initiatives such as US FIRST[5] or VEX Robotics Competition[6] frequently 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. To reach these students and avoid self-selection, recent work with the Arts & Bots program has been focused on integrating Arts & Bots in required core classes, such as history or language arts.

[5] US FIRST. USFIRST.org. Online, 2016. URL `http://www.usfirst.org`

[6] VEX Robotics, Inc. Competition - VEX - VEX Robotics, 2016. URL `http://www.vexrobotics.com/vex/competition`

The Arts & Bots program combines craft materials, a flexible hardware kit, an interactive software environment, and adaptable curriculum to empower students to create provocative, tangible sculptures with robotic actuation and sensing. An example robot is shown in figure 1.1. By providing a broad range of craft materials, we hope to promote a gender-neutral and creative design process, key features of Arts & Bots.

The Arts & Bots hardware kit was developed at the CREATE Lab[7] and is now commercially available through Birdbrain Technologies. At the heart of the hardware kit is the Hummingbird microcontroller, which was designed to support the Arts & Bots program.[8] The kit also includes outputs chosen to encourage the creation of compelling, expressive robots: DC motors, hobby servos, RGB LEDs, single color LEDs and vibration motors. The kit's sensors, chosen to support interactions with the robot, include those for: temperature, light, sound-level, and distance, as well as a potentiometer.

[7] Emily Hamner, Tom Lauwers, Debra Bernstein, Kristen Stubbs, Kevin Crowley, and Illah Nourbakhsh. Robot Diaries interim project report: Development of a technology program for middle school girls. Technical Report CMU-RI-TR-08-25, Carnegie Mellon University, Pittsburgh,PA, 2008a

[8] Tom Lauwers. *Aligning Capabilities of Interactive Educational Tools to Learner Goals*. PhD thesis, Carnegie Mellon University, 2010

This dissertation builds on prior work and preliminary results associated with Arts & Bots, and presents new work to develop and evaluate the identification and cultivation of student talents via Art & Bots. The prior work on Arts & Bots, described in more detail in chapter 3, covered the development of the hardware kit[9] and the evaluation of a small-scale out-of-school program.[10] Our more recent work covers the development and evaluation of the Arts & Bots program since we began adapting it for in-school environments in 2010. Since 2010, over 2400 students and over 360 educators have participated in Arts & Bots programs in Pennsylvania, Ohio, and

[9] Tom Lauwers. *Aligning Capabilities of Interactive Educational Tools to Learner Goals*. PhD thesis, Carnegie Mellon University, 2010

[10] Debra Lynn Bernstein. *Developing Technological Fluency through Creative Robotics*. PhD thesis, University of Pittsburgh, 2010

West Virginia, as well as internationally, in Brazil and the United Kingdom.

Research Questions and Hypotheses

In the past decade, the use of educational robotics tools to teach engineering and computer science concepts in schools has grown in popularity. This growth has initiated and supported research into the most effective classroom uses for these tools to achieve various educational goals. In this dissertation, we introduce one method for supporting students with creative robotics through our implementation of a performance-based student talent identification program. Our program also provides opportunities for talent-based learning that we define as leveraging understanding of a student's existing talent areas to encourage and motivate learning. To this end, our research aims to address two primary research questions:

- How can robotic systems be utilized in educational contexts to identify student talents, and thus promote talent-based learning?
- What design patterns and elements are instrumental in creating talent-based educational robotic systems?

In the original proposal for this thesis, we aimed to answer these research questions along three disparate axes of focus: diverse talent, system design, and teacher capacity. The resulting set of hypotheses were wide sweeping in scope and divided emphasis between the identification of all student talents, a detailed comparison of Arts & Bots to other educational systems, and the evaluation of the Arts & Bots teacher experience. However, after reconsideration, we decided that it would be more valuable to the field, and more authentic to the goals and capacity of the Arts & Bots research project, to refine our focus. We thus have narrowed our set of hypotheses to match the logical progression of the Arts & Bots program claims.

The primary hypotheses evaluated in this document are, therefore: *Identification Capacity*, *Talent Demonstration*, *Class Integration*, and *Program Affordances*. Each of the hypotheses is based upon its successors, as illustrated in figure 1.2 and described below.

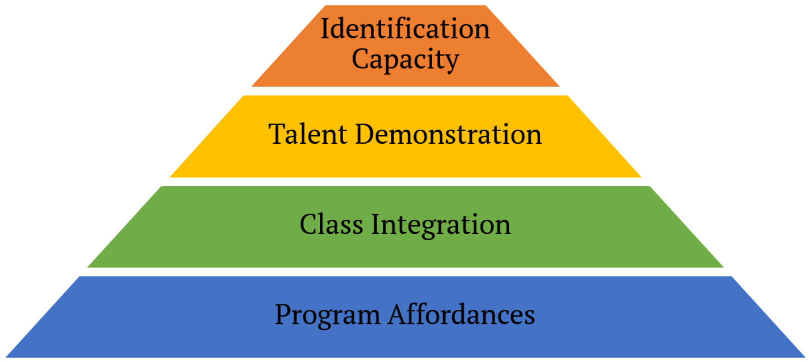

Figure 1.2: Structure of Dissertation Hypotheses

Our first claim is that it will be possible to build the capacity of non-technical teachers, and, subsequently, their schools, to identify and support student talents by using creative, educational robotics. This teacher skill is a critical element in the progression from student demonstration of talent to the recognition and identification of those talents.

Identification Capacity We hypothesize that a non-technical teacher provided with talent identification-oriented professional development, and a customizable, creative technology system increases their confidence and efficacy in identifying diverse student talent.

By participating in robotics projects that blend programming, engineering, design and communication tasks, students are provided with opportunities to demonstrate talents in these areas which can be recognized by trained teachers. We subsequently claim that by implementing these activities in classes where technology projects are not traditionally used, educators have new opportunities to observe students demonstrating talents that would otherwise go unnoticed.

Talent Demonstration We believe that creativity-oriented technologies can be used in educational contexts to provide students with opportunities to demonstrate a wide diversity of talents for teachers to identify.

We believe that it is possible to reach a larger number and greater diversity of students through the integration of a creative robotics project, like Arts & Bots, into non-technical classes. Integration goes beyond the self-contained use of robotics inside the context such classes and, instead, requires that robotics and the learning goals of the class topic are treated together to the mutual benefit of both. Further, for an integrated creative robotics program to remain sustainable beyond the scope of a research study, it must improve student performance within the discipline goals, to compensate for the extra time and effort that the robotics content will consume.

Class Integration We hypothesize that teachers can integrate creative robotics into non-technical class content, allowing us to provide robotics experiences to a wide diversity of students.

The final claim is that through our work to support class integration, talent demonstration, and identification capacity with the Arts & Bots program, we will refine Arts & Bots as a talent-based learning tool. We will be look to distill the primary affordances that allow this type of application.

Program Affordances We hypothesize that there exists a set of affordances in the Arts & Bots program that support talent-based learning, and in particular: classroom integration, student talent demonstration, and teacher identification capacity.

Contributions

The research presented here addresses two primary research questions:

- How can robotic systems be utilized in educational contexts to promote talent-based learning?
- What program elements are instrumental in creating talent-based educational robotic systems?

We describe in this dissertation the development and evaluation of the Arts & Bots program, with a particular focus on refining the program as a tool for identifying student talents and evaluating the role of educational robotics in talent-based learning. This document has eight primary chapters that address different elements of these research questions:

- Chapter 2 is a discussion of related fields of study, including the development of similar creative technology systems and programs focused on talented-student identification.
- Chapter 3 contains a summary of the early development of the Arts & Bots program, followed by overviews of the Arts & Bots Pioneers and Arts & Bots Math-Science Partnership studies and their respective research methods.
- Chapter 4 presents the process for the development of our teacher training model. It also details the final model as a contribution of the Arts & Bots program.
- Chapter 5 describes two case studies around a pair of classroom implementations, one in English language and the other in health and physical education.
- Chapter 6 discusses the design decisions made during the development of a new type visual programming software tool. This tool was developed for Arts & Bots with a focus on integrating robotics into non-technical classes.
- Chapter 7 describes the refinement of the Arts & Bots program as a talent identification tool, discusses the reference materials created for teachers — including handouts and a novice-built robot taxonomy — and presents analysis of outcomes resulting from these talent identification efforts.
- Chapter 8 discusses our process for developing evaluation tools — specifically those for students — to address Arts & Bots research goals and questions.
- Chapter 9 presents our analysis of these student evaluation tools, and describes student outcomes seen during Arts & Bots projects.

Together, the contributions of this work will be of value both to the development of future educational robotics programs and to our understanding of how teachers can incorporate the identification and support of student talents within their classroom. The principal contributions of this work will:

1. Present a model for how non-technical teachers can be trained to use robotics programs meaningfully in their classrooms
2. Fill knowledge gaps regarding implementation details of Arts & Bots in teacher-designed lesson plans and classrooms
3. Refine the Arts & Bots training program, materials and resources to emphasize talent-based learning.
4. Create a taxonomy of student- and teacher-generated Arts & Bots robots for analyzing and describing the interactions between the system and talent-based learning
5. Evaluate the effectiveness of Arts & Bots as a tool for talent-based learning and talent identification by individual students and their teachers.
6. Identify existing affordances of the Arts & Bots program that encourage talent-based learning, and develop design recommendations for augmenting the program's emphasis on talent-based learning.

2

Related Works

The Arts & Bots program presented here is distinguished by three principal features:

1. Performance-based talent identification

2. Engagement through robotics programs

3. Transdisciplinary integration with core subjects

These features highlight the numerous conceptual borders that Arts & Bots shares with a range of related research efforts, spanning the development of robotics technologies to studies on gifted and talented student education. While comprehensively describing all related fields is beyond the scope of this work, this chapter will introduce major related research by examining connections between the Arts & Bots program and a cross-section of similar programs.

Gifted and Talented Student Identification

The field of gifted and talented education is vast and evolving. There are many conflicting definitions of what it means for an individual to be gifted or talented. One commonly accepted, but outdated, definition is that the person scores in the 90th or 95th percentile in intelligence on an IQ test. There is no single federal definition of giftedness in the United States educational system, and most states also do not have standardized definitions or identification methods. However, 83.7 % of districts reported having a gifted program in a survey of

486 school districts.[1] Pfeiffer [2012] states that schools in the majority of states use teacher or parent referrals along with school administered standardized assessments, such as IQ tests, with cut-off scores for talented student identification.[2]

In contrast to the concept of students being "gifted" or "not gifted" based solely on intelligence metrics, Pfeiffer [2012] and Kaufman et al. [2009] explain that modern gifted education models instead present giftedness and student excellence as multifaceted concepts inclusive of creativity, persistence, and uncommon abilities in a least one domain.[3] Pfeiffer [2012] continues that giftedness is treated by experts as a mutable and developing quality. For instance, just because a young student is gifted does not mean they will be gifted through adulthood. Likewise, a young student who is not identified as gifted in elementary school may qualify as having exceptional abilities later on. Frasier et al. [1995] point out that standardized testing and intelligence-based metrics for giftedness may have biases that do not account for diverse student cultures and backgrounds – especially with regard to minorities underrepresented or underidentified for gifted intervention programs.[4]

Numerous research efforts have sought to correct for the imbalances in gifted identification and standardized assessment by using new programs and non-traditional assessment methods – namely alternative and performance-based assessment, as described by Sarouphim [2004].[5] Sarouphim goes on to present evaluation of the alternative assessment program, DISCOVER, which is a performance-based assessment designed to reflect Gardner's Multiple Intelligences theory and identify students in culturally diverse groups – in particular, students of Native American or Hispanic ethnicity. Lohman and Gambrell [2011] describe the use of non-verbal ability tests, traditionally used with English Language Learners (ELL) students.[6]

The National Association for Gifted Children [2011] defines gifted individuals as being those who "demonstrate outstanding levels of aptitude (defined as an exceptional ability to reason and learn) or competence (documented performance or achievement in top 10% or rarer) in one or more domains. Domains include any structured area

[1] Carolyn M Callahan, Tonya R Moon, and Sarah Oh. Status of Middle School Gifted Programs. 2013

[2] Steven I Pfeiffer. Current perspectives on the identification and assessment of gifted students. *Journal of Psychoeducational Assessment*, 30(1):3–9, 2012

[3] James C Kaufman, Scott B Kaufman, Roland A Beghetto, Sarah A Burgess, and Roland S Persson. Creative giftedness: Beginnings, developments, and future promises. In *International handbook on giftedness*, pages 585–598. Springer, 2009

[4] Mary M Frasier, Jaime H Garcia, and A Harry Passow. *A review of assessment issues in gifted education and their implications for identifying gifted minority students*. DIANE Publishing, 1995

[5] Ketty M Sarouphim. DISCOVER in middle school: Identifying gifted minority students. *Prufrock Journal*, 15 (2):61–69, 2004

[6] David F Lohman and James L Gambrell. Using nonverbal tests to help identify academically talented children. *Journal of Psychoeducational Assessment*, page 0734282911428194, 2011

of activity with its own symbol system (e.g., mathematics, music, language) and/or set of sensorimotor skills (e.g., painting, dance, sports)." [7] This concept of giftedness as a broad spectrum of potential domain talents is a powerful one. Further, Pfeiffer[8] described giftedness as "transforming [...] potential talent in specific culturally valued domains into outstanding performance and innovation in adulthood."

[7] National Association for Gifted Children. Redefining giftedness for a new century: Shifting the paradigm, 2011. URL `https://www.nagc.org/sites/default/files/Position%20Statement/Redefining%20Giftedness%20for%20a%20New%20Century.pdf`

[8] Steven I Pfeiffer. Current perspectives on the identification and assessment of gifted students. *Journal of Psychoeducational Assessment*, 30(1):3–9, 2012

While it is still common practice to treat the words *gifted* and *talented* as synonyms, Gagné [2004] describes giftedness as "the possession and use of untrained and spontaneously expressed natural abilities (called outstanding aptitudes or gifts), in at least one ability domain, to a degree that places an individual at least among the top 10 percent of age peers." [9] He goes on to distinguish talent as defined as "the outstanding mastery of systematically developed abilities (or skills) and knowledge in at least one field of human activity to a degree that places an individual at least among the top 10 percent of age peers who are or have been active in that field or fields." That is to say, where giftedness is a closely related to exceptional natural internal ability, talent is more about exceptional performance that can be developed with practice.[10] This concept of talent-as-expressed-through-performance is closely aligned with our *Talent Demonstration* hypothesis and will the assessment of such performance is integral to the *Identification Capacity* hypothesis .

[9] Françoys Gagné. Transforming gifts into talents: the DMGT as a developmental theory. *High ability studies*, 15(2): 119–147, 2004

[10] Note: This is an extremely important distinction in our descriptions of Arts & Bots and the research presented, which emphasizes the importance of identifying student **talents** through recognition of student performance.

It is possible for a student to possess talent in areas such as: solving math problems, playing baseball, watercolor painting, performing on the flute, or writing screenplays. However, while identifying students who have talents in common academic areas – such writing and math – is common practice for many educators, we seek to consider a new set of talents that reflect the culturally valued domains and innovative potentials of computer science, design, and engineering.[11]

[11] National Science Board. *Preparing the next generation of stem innovators: Identifying and developing our nation's human capital.* National Science Foundation, Arlington, VA, 2010

For the Arts & Bots program and the remainder of this document, we use the word *talent* to describe an individual's aptitude and mastery of a particular domain. This mastery can result from a multitude of sources including natural inclinations (e.g., giftedness), prior experiences, and environmental influences. Through our Arts & Bots project, we sought to develop definitions and models for computer science and engineering talents along with instruction programs, evaluation tools, and teacher training, and to study these models in use by practitioners. In no way is this program a comprehensive model of talent. Instead, we focus on helping schools identify talents in *Computational Thinking* and *Engineering Design*, two domains not traditionally taught in schools but very relevant to modern society.

Overview of K-12 Related Educational Systems

When evaluating the problem statement of this thesis, we considered related works on the development of similar educational technology systems. We categorize these systems into three related of which robotics systems are the most similar. The other two types – computing systems and engineering systems – bare strong resemblance but fall short being a complete robotic system. The foundation of this work is the educational robotics program Arts & Bots. Educational Robotics Systems – and robots in general – are an amalgamation of physical hardware with programming and software systems. Arts & Bots falls within this classification, being a combination of the Hummingbird Robotics Kit and an introductory programming environment, most commonly the CREATE Lab Visual Programmer. As such, it is relevant to examine the development of educational computing systems – in the form of introductory software programs – which lack the hardware basis to considered robotics. It is also useful to investigate educational engineering systems that are hardware-based and lack the computation aspects to be classified as robotics.

Educational Computing Systems

Since the introduction of personal computers, there has been a long lineage of computer programming languages designed to help students learn the basics of programming and computational thinking. These languages ease the transition to full-featured programming languages used in the software industry. One of the earliest introductory, text-based programming languages, created by Niklaus Wirth in 1970, was Pascal. Pascal was developed with the intent of introducing students to structured programming languages. Another example, Logo (introduced in 1967), was developed to teach concepts related to the use of the popular LISP programming language.It was used as the programming basis for early MINDSTORMS research prototypes, described in the *Educational Robotics Systems* section below.

Some newer introductory programming languages have taken advantage of the greater graphical interface capabilities of modern PCs. This permits the creation of programming environments that place the syntax within a wrapper of graphical representations that present numerous benefits.[12] One very popular visual programming language is Scratch, developed at the MIT Media Lab beginning in 2003. Scratch integrates the basic functions of procedural programming and some more advanced object-oriented programming concepts into a "jigsaw" puzzle graphical interface. This design decision teaches users that only certain types of code, represented as blocks, can be interfaced together.[13] For example, an *if-statement* block is constructed to contain a comparison operation, which cannot be replaced with a simple numeric variable. Scratch also takes an interdisciplinary approach, integrating the language closely with computer graphics and audio clips. This engages students interested in visual arts and music, by allowing them to create and program their own graphical animations and computer games. The integration of student interests and class subjects beyond computer programming was a critical feature in the development of Scratch, and informs the *Class Integration* and *Program Affordances* hypotheses described in our problem statement.

Another popular introductory programming language is Alice, developed as an object-oriented visual programming language.[14] Like Scratch, Alice also engages students with interdisciplinary integration of computer graphics, and thus helps to attract students interested in visual arts. In Alice, students are able to load visual graphic

[12] Margaret Burnett. Software engineering for visual programming languages. *Handbook of Software Engineering and Knowledge Engineering*, 2: 77–92, 2001

[13] John Maloney, Mitchel Resnick, Natalie Rusk, Brian Silverman, and Evelyn Eastmond. The Scratch programming language and environment. *ACM Transactions on Computing Education (TOCE)*, 10(4):16, 2010

[14] Matthew Conway, Steve Audia, Tommy Burnette, Dennis Cosgrove, and Kevin Christiansen. Alice: lessons learned from building a 3D system for novices. In *Proceedings of the SIGCHI conference on Human Factors in Computing Systems*, pages 486–493. ACM, 2000

objects and characters – such as an ice skater – and use preexisting object-oriented-style programming methods and functions to control those characters. More advanced students may also create their own methods and functions.

Other introductory programming languages, such as Greenfoot, Scheme, Python, Processing, and Calico fill out a spectrum of possible educational computer science systems ranging from procedural to object-oriented and from visual programming languages to popular, text-based programming languages such as Java, C#, and Visual Basic. This broad range of introductory programming languages offers learners of any skill level a variety of appropriate entry points into computer science activities and offers them a progression of tools to accommodate skill growth. We take inspiration from programming tools designed for the target learner group of Arts & Bots, middle school students.

Educational Engineering Systems

The complement to the introductory computer languages, environments and education computational systems, described above are electrical and mechanical engineering systems: physical tools and programs that support educators in teaching basic engineering concepts within their classrooms. Those tools frequently lower the barrier to entry for experiencing engineering design processes without existing knowledge of electrical or mechanical engineering, or fabrication skills.

Two widely available and popular mechanical systems are LEGO and K'Nex that allow users to build elaborate mechanisms and structures without relying on fabrication skills. These systems are often used by parents and educators to encourage creative play and fine motors skills. In schools, educators sometimes also use these systems to encourage their students to construct and explore simple machines and other concepts of mechanical and civil engineering.

Modern engineering systems are frequently associated with the contemporary Maker cultural phenomenon, which promotes a variation of technological fluency where people are encouraged to learn practical skills to make and modify technology creatively for their own purposes. One modern example a Maker system is littleBits, originally created by Ayah Bdeir.[15] The motivation behind littleBits was to create a system of electronics modules that can be easily combined, thus encouraging students to use the littleBits modules as a design material in the same way that crafts supplies seen as are a design material. Much like LEGO is used for building structures with little mechanical engineering experience, littleBits allows those with little electrical engineering experience to build circuits. The resulting system is one that uses small, modular, circuit-board-mounted components with magnetic couplers that provide polarized connections. The system incorporates a range of components, from simple switches and motors to more elaborate NOR gates, oscillators and microcontrollers. Snap Circuits is another modular electronic system, which is more geared towards analog circuits than littleBits, and provides less simplified interfaces between components.[16]

[15] Ayah Bdeir. Electronics as material: littleBits. In *Proceedings of the 3rd International Conference on Tangible and Embedded Interaction*, pages 397–400. ACM, 2009

[16] Elenco Electronics, Inc. Snap Circuits | Electronic and Educational Toys. Online, 2017. URL `http://www.snapcircuits.net/`

Cubelets, previously called roBlocks, is a robotics kit that, similar to littleBits, uses magnetic connections to interface between electronic components, sensors and outputs to construct electronic circuits.[17] Using distributed programming, each cube-shaped module of the device communicates to its neighbors with an electrical signal. Some cubes modify the signal (e.g., inverting the signal) received before passing it on to its neighbors. Other cubes perform an action (e.g., produce a sound) based on the signal received. Robots can be built and programmed by placing various combinations of cubes together. The physical arrangement of these modules impacts both the form and function of the robot. While this kit is oriented towards the creation of robotic devices, the absence of an explicit computer programming interface led to its classification as an exclusively physical engineering system over a robotics system.

[17] Eric Schweikardt and Mark D Gross. roBlocks: a robotic construction kit for mathematics and science education. In *Proceedings of the 8th International Conference on Multimodal Interfaces*, pages 72–75. ACM, 2006

Engineering is Elementary is another example of an educational engineering program . However, unlike the others, it's not merely single hardware system, but is instead a program of 20 curriculum units for integrating engineering into a variety of elementary classroom science topics, namely life science, earth and space science and physical science.[18] These units include lesson plans and assessments around an engineering design activity and a materials kit with most of the supplies that a teacher would need to implement that activity in their classroom. For example, there is a unit called "The Best of Bugs: Designing Hand Pollinators" which can be integrated into a class that is studying insects. The engineering activity revolves around the design and construction of a tool to pollinate flowers like an insect would,and helps teachers to motivate the activity, discuss engineering, and complete the design task.

In general, these engineering systems are more challenging to summarize as a category as the purpose, goals, approach and structure of each system can vary dramatically. Whereas the computational systems share a common medium and related computer science goals, the relationship between mechanical kits like LEGO and electronics kits like littleBits is more abstract. In our Arts & Bots program, we take inspiration from existing educational engineering systems by providing students compatible hardware components that allow novices to create functioning robots without prior electronics experience. By combining these components with craft materials, we aim to blur the line for novices between creating a craft sculpture and the mechanical construction of a robot.

[18] Cathy P. Lachapelle and Christine M. Cunningham. Engineering in elementary schools. In Şenay Purzer, Johannes Strobel, and Monica E. Cardella, editors, *Engineering in Pre-College Settings: Synthesizing Research, Policy, and Practices*. Purdue University Press, Lafayette, IN, 2014

Educational Robotics Systems

Educational robotics systems bring together the hardware of educational engineering systems and the programming of educational computing systems, as described above. LEGO MINDSTORMS is one of the most popular educational robotics programs in the United States and thus a reasonable system to examine first in our consideration of related robotics systems. MINDSTORMS is the basis for the FIRST LEGO League, a middle school precursor to the international high school robotics competition FIRST. FIRST LEGO League has been rapidly growing in size. In the United States, 4000 teams competed in 2003 and, in 2012, the number grew to 12,000 teams.[19]

Early work on the development of LEGO MINDSTORMS System is discussed in LEGO, Logo, and Design.[20] Here, researchers show

[19] Center for Youth and Communities. Evaluation of the FIRST LEGO®League "Senior Solutions" Season (2012-13) - Executive Summary. Online, 2013. URL `http://www.usfirst.org/aboutus/impact`

[20] Mitchel Resnick, Stephen Ocko, and Seymour Papert. LEGO, Logo, and design. *Children's Environments Quarterly*, pages 14–18, 1988

the development of an interface between the educational programming environment Logo and physical LEGO creations, featuring light sensors, touch sensors, lights, and motors for powering mechanisms. The authors observed the broad appeal of the program to students, as well as, intrinsic differences among the students. Students attracted to different project types exhibited different design styles. This observation is closely aligned with the *Talent Demonstration* hypotheses set out in the problem statement of our work, as it indicates that the students were able to explore different interest areas while using LEGO/Logo. That these different styles of engagement were observable by the researchers, allowing them to identify the student interests and talents, is also supportive of our *Identification Capacity* hypothesis.

By 1993, over a million students had utilized LEGO/Logo in their schools.[21] To introduce parallel behaviors and untether LEGO robots, Electronic Bricks were introduced, which possessed similar light sensors, touch sensors, motors, and lights, contained within LEGO bricks with integrated circuitry for basic controls. There were additional blocks that performed basic logic between the input and output bricks like and-gates and flip-flops. This permitted simple, untethered robot behaviors to be created by manipulating the physical connection paths between the sensors and outputs.[22] From the Electronic Bricks grew the concept of the Programmable Brick, which took the discrete single function logic bricks, and replaced them with a programmable microcontroller with control for four outputs and eight sensors, in addition to a built-in speaker, microphone and IR communication.[23] Students created programs on a personal computer and downloaded that program to the controller brick for untethered operation. In 1998, LEGO released the commercially available LEGO MINDSTORMS robotics kit with a programmable brick which featured three input and three output ports.

The development of two related programming interfaces for controlling LEGO devices with computers, LEGO Engineer and ROBOLAB, are presented in "Middle School Engineering with LEGO and LabView"[24] and "Lego Engineer and ROBOLAB: Teaching Engi-

[21] Mitchel Resnick. Behavior construction kits. *Communications of the ACM*, 36 (7):64–71, 1993

[22] Mitchel Resnick. Behavior construction kits. *Communications of the ACM*, 36 (7):64–71, 1993

[23] Mitchel Resnick. Behavior construction kits. *Communications of the ACM*, 36 (7):64–71, 1993

[24] Ben Erwin, Martha Cyr, John Osborne, and Chris Rogers. Middle school engineering with LEGO and LabVIEW. In *Proceedings of National Instruments Week*, Austin, TX, 1998

neering with LabView from Kindergarten to Graduate School".[25] Both of these programming interfaces were based on the LabView programming language that use a visual representation of data flow to allow users to program logic controlled data paths between sensors and outputs. LEGO Engineer was created to control the LEGO Control Lab Interface: a PC tethered LEGO interface with 8 ports for inputs (touch, light, temperature and rotation sensors) and 8 outputs (motors and lights). The ROBOLAB interface, on the other hand, was designed for LEGO to control the previously mentioned untethered RCX bricks. It was created specifically for in-school environments since it featured cross-platform compatibility, a lower barrier-to-entry and higher ceiling than the visual programming interface that accompanied the MINDSTORMS kit sold to individuals.[26] These qualities are demonstrated by diverse case studies which illustrate the system being used for meaningful projects by both kindergarten students and graduate level students.

[25] Ben Erwin, Martha Cyr, and Chris Rogers. LEGO engineer and ROBOLAB: Teaching engineering with LabVIEW from kindergarten to graduate school. *International Journal of Engineering Education*, 16(3):181–192, 2000

[26] Ben Erwin, Martha Cyr, and Chris Rogers. LEGO engineer and ROBOLAB: Teaching engineering with LabVIEW from kindergarten to graduate school. *International Journal of Engineering Education*, 16(3):181–192, 2000

Figure 2.1: A insect-like, walking robot built with LEGO MINDSTORMS by Mario Ferrari. (`www.marioferrari.org/lego/brlm/brlm.html`)

The popularity of LEGO MINDSTORMS programs is demonstrated by the breadth of research based on the system. For example, in "RoboCup Jr. with LEGO MINDSTORMS"[27], the authors present a robot soccer competition developed for 7 to 14 year olds that is based on the use of LEGO MINDSTORMS. In "LEGO Mindstorms: Not just for K-12 anymore"[28], the authors outline the overlap between topics of the ACM/IEEE Computing Curriculum 2001 for undergraduates and the pedagogical possibilities of LEGO MINDSTORMS as a tool in college computer science classes. Another example is presented in "Engineers and storytellers: Using robotic manipulatives to develop technological fluency in early childhood"[29], where the author describe case studies of LEGO MINDSTORMS robots created by elementary school students that demonstrate differences in student interests, and describes the young students as "little storytellers" and "little engineers." The differentiation between the styles of engagement that students in this study demonstrate with the MINDSTORMS system is, again, indicative that students use different talents. The case study examples show that these talents are being

[27] Henrik Hautop Lund and Luigi Pagliarini. Robocup Jr. with LEGO MINDSTORMS. In *2000 IEEE International Conference on Robotics and Automation (ICRA)*, pages 813–819, 2000

[28] Frank Klassner and Scott D. Anderson. LEGO MINDSTORMS: Not just for K-12 anymore. *IEEE Robotics & Automation Magazine*, 10(2): 12–18, 2003

[29] Marina U. Bers. Engineers and storytellers: Using robotic manipulatives to develop technological fluency in early childhood. In Olivia N Saracho and Bernard Spodek, editors, *Contemporary Perspectives on Science and Technology in Early Childhood Education*, pages 105–225. IAP, 2008

expressed through the students' robotics projects — substantiating our *Talent Demonstration* hypothesis.

Following the development of the Programmable Brick, the Lifelong Kindergarten group at the MIT Media Lab developed a related programmable device called a PicoCricket. The PicoCricket serves as the basis of an educational robotics kit that places more focus on artistic expression than LEGO MINDSTORMS.[30] In the proposal "Rethinking robotics: engaging girls in creative engineering," the PicoCricket is compared to the LEGO MINDSTORMS RCX controller:

[30] Natalie Rusk, Mitchel Resnick, Robbie Berg, and Margaret Pezalla-Granlund. New pathways into robotics: Strategies for broadening participation. *Journal of Science Education and Technology*, 17(1): 59–69, 2008

> "[...] the RCX focuses on controlling motors while Crickets also allow for more expressive output (with colored lights, music, and sound). So while LEGO Mindstorms is ideally suited for robot competitions, Crickets are ideally suited for the artistic creations at the heart of Cricket Craft Clubs."[31]

[31] Natalie Rusk, Robbie Berg, and Mitchel Resnick. Rethinking robotics: engaging girls in creative engineering. *Proposal to the National Science Foundation*, 2005

Specifically, the motors of LEGO MINDSTORMS make it particularly well suited for small mobile robots typically used in competitions, while the PicoCricket was designed to integrate art and technology by providing aesthetic and audio outputs (lights and speakers respectively). In "New Pathways into Robotics"[32], the authors describe the use of PicoCrickets as a method for engaging students who are not interested in traditional robotics programs and competitions, by providing connections to robotics through other interests, like music, art and storytelling. Our work takes particular inspiration from the development of and the impact achieved by the PicoCricket program.

[32] Natalie Rusk, Mitchel Resnick, Robbie Berg, and Margaret Pezalla-Granlund. New pathways into robotics: Strategies for broadening participation. *Journal of Science Education and Technology*, 17(1): 59–69, 2008

The PicoCricket system was put into practice through three separate educational programs: a workshop for families, an after-school program, and a professional development workshop for educators. Within these three programs, the authors utilized four key strategies that aid their programs in engaging diverse audiences. These strategies are: Focus on Themes (Not Just Challenges), Combine Arts and Engineering, Encourage Storytelling and Organize Exhibitions (Rather than Competitions).

Artbotics is an educational robotics program — similar to the PicoCricket — that was created at University of Massachusetts

Lowell. Artbotics was based on the SuperCricket microcontroller, a variation of the PicoCricket that supported a great variety of outputs and was programmed initially using Logo.[33] The Artbotics Program was initially implemented in a high school after-school program in 2007, and has since grown to incorporate various educator workshops, and transitioned to the LEGO MINDSTORMS system as the primary microcontroller since it is widely available commercially and is already accessible to teachers in many schools.

[33] Holly A Yanco, Hyun Ju Kim, Fred G Martin, and Linda Silka. Artbotics: Combining art and robotics to broaden participation in computing. In *AAAI Spring Symposium: Semantic Scientific Knowledge Integration*, page 192, 2007

Each of these creative educational robotics systems support the construction of completely unique robots, based on sets of materials and basic robotics components. This provides great hands-on design and engineering experience, but comes at the cost of classroom and instructional time. Construction, testing, and revisions to the constructed robots consume large blocks of time before students can program their robot behaviors. A number of different robotics systems have developed as specialized tools for encouraging students to engage at a deeper level with introductory computer science (CS) tasks, by providing a tangible interface to the computation concepts. One such CS-oriented robotics system, the Finch robot, was designed to be integrated into Introductory CS classes with maximal engagement and minimal distraction to the Computer Science curriculum taught in introductory high school and college level computer science classes.[34] This is supported, in part, by removing the robot construction aspect of the system — instead presenting students with a prepackaged robotic system that is ready to be programmed out of the box. Another such pre-constructed CS-oriented robotics system is the Scribbler robot, produced by Parallax Inc, which is the central hardware of the Institute for Personal Robots in Education at Bryn Mawr and Georgia Tech.[35] In both cases, it is possible to customize these prebuilt robots with various craft materials, permitting but not requiring students to personalize and form a deeper investment in the projects.

[34] Tom Lauwers and Illah Nourbakhsh. Designing the Finch: Creating a robot aligned to computer science concepts. In *AAAI Symposium on Educational Advances in Artificial Intelligence*, volume 88, 2010

[35] Tucker Balch, Jay Summet, Doug Blank, Deepak Kumar, Mark Guzdial, Keith O'Hara, Daniel Walker, Monica Sweat, Gaurav Gupta, Stewart Tansley, et al. Designing personal robots for education: Hardware, software, and curriculum. *IEEE Pervasive Computing*, 7 (2), 2008

Professional Development and Teacher Training

Prior and ongoing research efforts have investigated the best practices for K-12 teacher training, both at an undergraduate level for pre-service teachers, and beyond as professional development (PD) for in-service teachers. These research efforts help to inform our *Identification Capacity* hypothesis and our development of the Arts & Bots teacher training model presented in chapter 4. Desimone [2009][36] determined that there are five critical components of effective professional development:

[36] Laura M Desimone. Improving impact studies of teachers' professional development: Toward better conceptualizations and measures. *Educational researcher*, 38(3):181–199, 2009

Content Focus: PD is focused on concepts applicable to the teachers' content areas

Active Learning: PD features active learning activities, as opposed to just passive learning such as a traditional lecture format.

Coherence: PD instruction must be coherent with the teacher's existing knowledge, experience, and beliefs.

Duration: PD must also be of adequate duration to have the most potential benefit: at least 20 hours of instruction.

Collective Participation: Teachers benefited most from attending PD with their peers — in particular multiple educators should attend from the same school, grade level, or department.

Martin et al. [2010][37] saw connections between features of high fidelity PD, i.e. professional development closely matched to program goals, and students outcomes. The primary features of high fidelity professional development framed by this research were: modeling instruction, community building, technology utilization, connection to practice, and inquiry-based learning. Modeling instruction during professional development involves using the instructional methods for teachers are expected to use for student instruction. The PD is conducted in a way that encourages and supports teacher collaboration. The PD instruction uses the technology being presented both to support the training and completing activities during the PD. The PD instructors and the teachers make connection to the teachers'

[37] Wendy Martin, Scott Strother, Monica Beglau, Lauren Bates, Timothy Reitzes, and Katherine McMillan Culp. Connecting instructional technology professional development to teacher and student outcomes. *Journal of Research on Technology in Education*, 43 (1):53–74, 2010

practice. Finally, the PD incorporates activities like planning inquiry, as well as, gathering, analyzing, and presenting data. They found that modeling practice was a strong predictor of lesson plan quality, and that all factors of high fidelity PD were correlated with higher student test scores.

Other research efforts have sought to develop models to bring computer science training to K-12 teachers. Cortina and Trahan [2013][38] led five-day computer science workshops for teachers in 2009, 2010, 2011, and 2012 for a total of approximately 240 teachers, and saw increases for self-reported ability to teach computer science content and to integrate of the content into their courses. Zhou et al. [2015][39] designed robotics-oriented professional development that focused on helping teachers, who already used robotics in extracurricular clubs, to integrate robotics lessons into interdisciplinary classroom curriculum. Martin et al. [2015][40] designed and studied a six-week training workshop on design-engineering for math and science teachers, which consisted of a four major units: vehicle design, reverse engineering and product redesign, robotics, and a final design capstone. Through this design-based instruction training, the authors saw improvements in the teachers' design-engineering factual knowledge and problem solving ability, as well as, teachers' adaptive beliefs about engineering content and design. However, they did not see changes in teachers' beliefs about how engineering is learned.

The findings and recommendations of the professional development research presented above helped to inform our creation of professional development for Arts & Bots, as part of the *Program Affordances* hypothesis. Our *Identification Capacity* hypothesis is also founded training teachers to identify student talents during Arts & Bots professional development.

[38] Thomas J Cortina and Keith Trahan. Increasing computing in high school through STEM teacher workshops. *International Society for Technology in Education (ISTE)*, 2013

[39] Hong Zhou, Timothy T Yuen, Cristina Popescu, Adrienne Guillen, and Don G Davis. Designing teacher professional development workshops for robotics integration across elementary and secondary school curriculum. In *Learning and Teaching in Computing and Engineering (LaTiCE), 2015 International Conference on*, pages 215–216. IEEE, 2015

[40] Taylor Martin, Stephanie Baker Peacock, Pat Ko, and Jennifer J Rudolph. Changes in teachersâĂŹ adaptive expertise in an engineering professional development course. *Journal of Pre-College Engineering Education Research (J-PEER)*, 5(2):4, 2015

3

Overview of Arts & Bots Program, User Studies, and Data Collection

Development of Robot Diaries

The Arts & Bots project began in 2006 under the moniker "Robot Diaries". Robot Diaries was an out-of-school program focused on engaging more middle-school girls with technology, computer science, and engineering.[1] This focus was motivated by the under-representation of women in computer science, epitomized by the Computer Research Association Taulbee Survey in 2006 which reported an alarming downward trend — over 6% from 2001(18.8%)[2] to 2006(12.2%) — in the percentage of computer science bachelor's degrees being granted to women.[3] The middle school group was selected because this developmental age range has been shown to be the critical time for enacting effective change. Students at this stage develop self-identity, which impacts their decisions and pathways to future course enrollment and careers.[4] In particular, Robot Diaries sought to bring robotics and technology experiences to middle school girls who were not otherwise drawn to existing technology programs.

Robot Diaries studies began in 2006, and consisted of a focus group followed by a series of participatory design workshops. The focus group was a two-hour session with seven girls aged 11 to 14 years old.[5] The subsequent 2-hour participatory design workshops, held in the summer and fall of that year, engaged between two and

[1] Emily Hamner, Tom Lauwers, Debra Bernstein, Kristen Stubbs, Kevin Crowley, and Illah Nourbakhsh. Robot Diaries interim project report: Development of a technology program for middle school girls. Technical Report CMU-RI-TR-08-25, Carnegie Mellon University, Pittsburgh,PA, 2008a

[2] Moshe Y Vardi, Tim Finin, and Tom Henderson. 2001-2002 Taulbee survey: Survey results show better balance in supply and demand. *Computing Research News*, 15(2):6–13, 2003

[3] Stuart Zweben. 2006-2007 Taulbee Survey: Ph. D. Production Exceeds 1,700; Undergraduate Enrollment Trends Still Unclear. *Computing Research News*, 2008

[4] Jill Denner, Linda Werner, Steve Bean, and Shannon Campe. The girls creating games program: Strategies for engaging middle-school girls in information technology. *Frontiers: A Journal of Women Studies*, 26(1):90–98, 2005

[5] Tom Lauwers. *Aligning Capabilities of Interactive Educational Tools to Learner Goals*. PhD thesis, Carnegie Mellon University, 2010

eight girls each.[6] Lauwers [2010] describes how the findings and program goals refined during these studies led to the development of the Hummingbird microcontroller. Its the hardware kit, and a software programming tool called Express-o-Matic, which was the predecessor to the CREATE Lab Visual Program which is described in chapter 6.

[6] Emily Hamner, Tom Lauwers, Debra Lynn Bernstein, Illah R. Nourbakhsh, and Carl Disalvo. Robot Diaries : Broadening Participation in the Computer Science Pipeline through Social Technical Exploration. In *Proceedings of the AAAI Spring Symposium on Using AI to Motivate Greater Participation in Computer Science*, 2008b

Following the development of the hardware and software elements of the Robot Diaries kit, the research team turned their attention to the creation of a stand-alone curriculum package for extracurricular workshops. This curriculum was then piloted with two community groups, the People Always Learning Something (PALS) home school group and the Sarah Heinz House.[7] Bernstein [2010] describes in detail the evaluation of the PALS pilot, which was led by two instructors from the program and involved seven middle school girls over the course of six three to four-hour sessions. The Sarah Heinz house program was also taught by two instructors and involved ten middle school girls in sixteen one-hour classes.

[7] Tom Lauwers. *Aligning Capabilities of Interactive Educational Tools to Learner Goals*. PhD thesis, Carnegie Mellon University, 2010

During these studies, results suggested that participants in Robot Diaries generally showed an increase in confidence working with technology but did not show any global change in their levels of interest. Researchers hypothesized that students who enrolled in these Robot Diaries pilots already possessed established interests in robotics and technology. Thus, while Robot Diaries was successful in engaging the enrolled students, as an out-of-school program it suffered from self-selection.

This led to our decision to reprogram Robot Diaries as "Arts & Bots" and to focus on in-school settings to reach a broader student audience and increase impact. While the initial focus of Robot Diaries was on girls, Arts & Bots now aims to appeal to both genders. Middle school remains the primary target age group, although the program has also been successfully utilized more broadly throughout K-12 in-school and out-of-school settings.

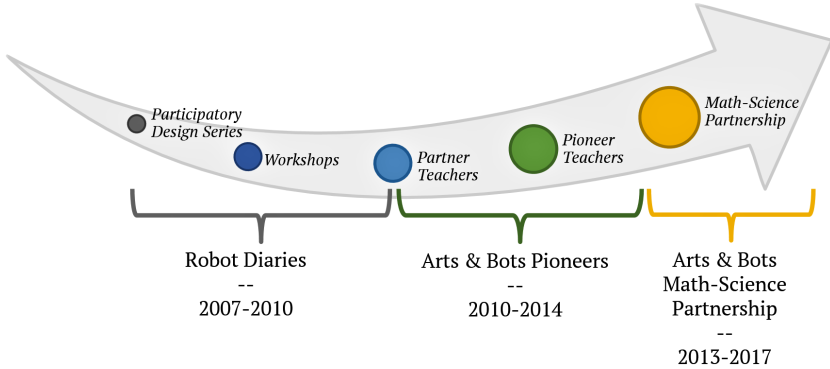

Figure 3.1: The sequence and growth of the Arts & Bots project, since the start of the Robot Diaries program in 2007.

Arts & Bots Pioneers Program

In the summer of 2010, over the course of a six-week partner residency program, two teachers were recruited to collaborate on the adaptation of the Robot Diaries for in-school settings. Their residency is described in chapter 4, in the section titled "2010 Partner Teachers." Following two initial classroom pilots, one by each partner teacher, we initiated the Arts & Bots Pioneers, program which involved 10 "pioneering" non-technical teachers (including the original two partners), who first participated in a six-day graduate-level course in the summer of 2011, and then brought the Arts & Bots program into their classrooms. While not all of the Pioneer teachers were able to pilot Arts & Bots in their classes following this professional development because of limited resources, we were able to collect data in 13 classes. These included six 7th grade classes covering: Accelerated Language Arts, Advanced Math, History, and Technology Education, as well as seven 8th grade classes covering Academic and Accelerated Language Arts. Academic Language Arts was the standard grade-level English course. Accelerated Language Arts was an honors course for higher performing students (approximately the top 25% of student) and covered material at a faster rater permitting greater breadth and depth of content. Data were collected between November 2010 and April 2014 and were collected from six schools: five public and one independent; a mix of rural (n=3), suburban (n=2), and urban (n=1). We collected data during these classes through student pre- and post-surveys, limited teacher and student interviews, and a few class observations. Our analysis of this data is presented in chapter 9.

The Pioneers teachers frequently made the anecdotal observation that Arts & Bots allowed them to identify skills and interests of their students that were otherwise not demonstrated in their non-technical classes. One teacher of seventh and eighth grade language arts remarked, "It was nice for me as a teacher to see a different side of them. Sometimes we get caught up in our content because of course that's our passion [...] It was nice to see their passions for something else and [see] them in a different light." This recurring trend by teachers to notice and informally note student talents, led to the formation of a new research study and a partnership of organizations and schools to formally evaluate the utility of Arts & Bots as a tool for helping teachers and schools to identify and develop student talents and interests in engineering and computational thinking.

Creative Robotics Math-Science Partnership Program

The resulting partnership, launched in fall 2013, was a joint collaboration combining the teacher training expertise of Marshall University's June Harless Center for Rural Educational Research and Development, West Liberty University's Center for Arts & Education, the engineering and technology development expertise of the Carnegie Mellon CREATE Lab, and district-wide support from a suburban school district in Pennsylvania and a rural school district in West Virginia. The partnership's primary focus was the expansion and evaluation of Arts & Bots as a tool for helping to identify student talents and interests in engineering and computing concepts. The initial goal was the implementation of Arts & Bots in required courses, such that all 7th and 8th grade students would participate, thus eliminating the self-selection seen in elective courses and extracurricular activities, like Robot Diaries. In addition, by working with entire school districts, we aimed to develop district-wide models for talent identification and support efforts across multiple classes and grade levels.

Teachers participating in the partnership received approximately two days of professional development each year. Between 2014 and 2017, 24 teachers from the two districts completed Arts & Bots projects in 66 classes. We assigned these class projects with implementation codes, which cluster projects taught by the same teacher for the same class topic simultaneously. For example, if teacher completed Arts & Bots in three Language Arts 7 classes at first, fourth and sixth period during the same time frame, those three classes were counted as a single implementation. There were 43 separate project implementations during the same time frame. These projects involved 776 unique students. Of those students, 322 students were from the suburban school district and 454 students were from the rural school district. Some students participated in more than one implementation, such that there were 1273 separate student experiences.

Data Collection Tools

The Arts & Bots Pioneers and Arts & Bots Math-Science Partnership studies both followed the paradigm of mixed-methods research studies. Our collection of quantitative data allows us to take into account the outcomes of a wide breadth of student and teacher experiences. Meanwhile, the collection of qualitative data allows us to achieve a deeper understanding of those projects, experiences and outcomes. We have developed several tools to support the summative and formative evaluation of the Arts & Bots program, including measurements of teacher student-talent identification skills, student self-efficacy, student attitudes towards robotics, and other metrics of Arts & Bots program success. The development of our student survey content is discussed further in chapter 8.

Mixed methods research is defined by Johnson et al. [2007] as a "type of research in which a researcher or team of researchers combines elements of qualitative and quantitative research approaches (e.g., use of qualitative and quantitative viewpoints, data collection, analysis, inference techniques) for the broad purposes of breadth and depth of understanding and corroboration."

R Burke Johnson, Anthony J Onwuegbuzie, and Lisa A Turner. Toward a definition of mixed methods research. *Journal of mixed methods research*, 1(2): 112–133, 2007

Table 3.1: Pioneers Study Data Collection Tool Types and Timing

Middle School Student Data	
Tool Type	**Collection Time**
Student Demographics Questionnaire	Pre-Project
Pilot Robotics Activities Attitudes Scale (RAAS)	Pre & Post
Input-Output-Processing Systems Concept Scale	Pre & Post
Pilot Hardware Component Recognition and Understanding Scale	Pre & Post
Student Final Presentation Observations	Post-Project
Partner Teacher Data	
Tool Type	**Collection Time**
Course Deliverables	During PD
Teacher Interview	Post-Project

Arts & Bots Pioneers Study Data Collection

Arts & Bots Math-Science Pioneers teachers received training on Arts & Bots during a 6-day course, as described in chapter 4. During this course, the teachers produced deliverables that documented possible project ideas, and prototype curriculum materials. Once the teachers returned to their schools, the data collected from the Arts & Bots projects primarily focused on student outcomes. The day before each project started, the students would complete an online pre-survey. This pre-survey was a composite of all the pre-project tools for middle school students listed in table 3.1. On the last day of the project, we would visit the class in order to observe student final project presentations and collect photos of the final robots. Following their completion of the project, the students took an on-line post-survey and we interviewed the teachers about the project and their experiences.

Arts & Bots Math-Science Partnership Study Data Collection

Arts & Bots Math-Science Partner teachers also received training on Arts & Bots as described in chapter 4. This training took place approximately once per year, and was offered as initial training to new participants. Established Arts & Bots teachers also attended the training workshops annually, which allowed them to participate in the latest training activities, to practice Arts & Bots skills, to prepare their Arts & Bots projects for the new year, and to discuss their Arts & Bots experiences with peers. Before the start of these annual training workshops, teachers were asked to complete a survey measuring their self efficacy with regard to: Art & Bots concepts, integrating Arts & Bots with their classes, and identifying student talents. Following the training workshops, the teachers then completed a similar post-survey. The post-survey also documented topics the teachers would like to cover in training in the future.

Each of the school districts managed their own set of Arts & Bots program materials, including the robotics hardware kits, craft materials, and laptop computers. The sharing of these materials was coordinated between teachers in order to ensure that the planned Arts & Bots projects would fit into each course at the appropriate time. Teachers at the suburban school district benefited logistically in two ways: 1) being geographically co-located within two neighboring school buildings, and 2) having a gifted education teacher serving as a single point-of-contact and coordinator for distribution and maintenance of the Arts & Bots materials. Teachers at the rural district faced more logistical barriers caused by the geographical separation of the participating schools. This resulted in a resource-management process where responsibility for the Arts & Bots materials was distributed among the teachers.

One month before their scheduled project start time, teachers were contacted by the research team and reminded of the data collection tools and schedule, summarized in table 3.2. Two weeks before the start of the Arts & Bots project, the teacher would complete their first talent inventory (described in more detail in chapter 7). On the day before the start of the project, the teachers would complete their second talent inventory, and the students would take an online pre-survey. This pre-survey was a composite of all the pre-project tools for middle school students listed in table 3.2.

During the project, students were asked to complete an exit ticket each day and, in many classes, the classroom activity was video taped or observed by researchers when possible. The teachers also filled out a class implementation log documenting class activities during the project. Following completion of the project, the teachers were asked to complete a third and final talent inventory of their

Table 3.2: MSP Study Data Collection Tool Types and Timing

Middle School Student Data	
Tool Type	**Collection Time**
Student Demographics Questionnaire	Pre-Project
GRIT Questionnaire	Pre-Project
Robotics Activities Attitudes Scale (RAAS)	Pre & Post
Input-Output-Processing Systems Concept Scale	Pre & Post
Hardware Component Recognition and Understanding Scale	Pre & Post
Engineering, Technology & STEM Career Perceptions	Pre & Post
Exit Flow Questionnaire	During Project
Expectation Comparison Questionnaire	Post-Project
Student Portfolio & Design Documentation	Post-Project
Student Time Spent Questionnaire	Post-Project
Partner Teacher Data	
Tool Type	**Collection Time**
Teacher Professional Development Survey	Pre & Post-PD
Early Talent Inventory	Two weeks before start
Talent Inventories	Pre & Post-Project
Teacher Implementation Log	During Project
Teacher Interview	Post-Project
Final Teacher Survey	Post-Project
Classroom Project Data	
Tool Type	**Collection Time**
Classroom Observation Protocol	During Project
Project Calendar	During Project

students while the students filled out online post-surveys. At the end of the project, we collected any student design portfolios, photos of complete robots, project rubrics or hand-outs that the teachers were able to provide us. Finally, each teacher was interviewed about their experiences during the project.

4
Teacher Training

As engineering, computational thinking, and technology development are not integrated into traditional K-12 teacher training programs in the United States, a new pathway must be developed to prepare teachers from traditional disciplines, such as English, History or Science, for the inclusion of engineering and computational activities in the classroom.

In this chapter, we report on a Professional Development (PD) model designed to help teachers integrate robotics projects into disciplinary classrooms, and to promote teacher skill, confidence, and self-efficacy in the development and classroom implementation of robotics design projects. Teacher training integrates experience with robotics kit components, a programming interface, the engineering design process, and recognition of student talents in engineering and computer science. We present the development model for our teacher training program as well as results regarding teacher practice and self-efficacy. Data includes teacher surveys, interviews, and class observations. Additionally, teacher training has developed over the course of several years, and we discuss how teacher experiences have shaped the development of the program into its current form.

Portions of this chapter first appeared in:

Hamner, E., Cross, J., Zito, L., Bernstein, D., & Mutch-Jones, K. (2016). Training teachers to integrate engineering into non-technical middle school curriculum. In 2016 IEEE Frontiers in Education Conference (FIE).

Table 4.1: Schedule of 2010 six-week Partner Teacher Residency

Time	Topic
Week 1	Introduction to Arts & Bots Hardware Practice building multiple robots Introduction to Arts & Bots Software Robot Art Tours and Talks Creating mini assignments
Week 2	Deliver sample mini assignment lessons to a practice class Design scope of two curriculum plans Identify standards for each curriculum
Week 3	Design first two units of each curriculum Create supporting materials, including slides and videos
Week 4	Pilot delivering curriculum units 1 Develop units 3 and 4 of each curriculum Create supporting materials, including slides and videos
Week 5* *partial week	Pilot delivering curriculum units 3 and 4 Make feedback-based revisions to curriculum units 1 to 4
Week 6	Develop units 5 and 6 of each curriculum Pilot delivering curriculum units 5 and 6 Create remaining supplementary materials, including handouts and rubrics Make final revisions to curriculum units 1 to 6

Evolution of Professional Development

2010 Partner Teachers

Earlier Arts & Bots pilot studies were focused on out-of-school environments and participatory design activities.[1] In 2010, Arts & Bots switched its focus to in-school environments where a broader population of students could be reached by avoiding self-selection.[2]

As described in chapter 3, in the summer of 2010, following the out-of-school participatory design phase, and recognizing the benefits and challenges of working in schools, the Arts & Bots program recruited 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 the research team 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.

During the 2010/11 academic year, as part of the initial in-school pilot, we collected evaluation data while the two teachers piloted

[1] Emily Hamner, Tom Lauwers, Debra Bernstein, Kristen Stubbs, Kevin Crowley, and Illah Nourbakhsh. Robot Diaries interim project report: Development of a technology program for middle school girls. Technical Report CMU-RI-TR-08-25, Carnegie Mellon University, Pittsburgh,PA, 2008a

[2] Illah Nourbakhsh et al. Robot Diaries: Co-design of creative technology and middle school curriculum. Proposal to the National Science Foundation, 2009

their curricula in their classes. The student data collected during these classes were used to inform modifications to the Arts & Bots software, hardware, and evaluation tools. In these pilot classes, teachers also provided feedback necessary to improve the functionality and ease-of-use of the hardware and software for in-school environments.

Table 4.2: Schedule of 2011 six-day Teacher Training Mini-Course

Schedule	Topic
Day 1	Educational Robotics Overview Activity with PicoBoard & Scratch Introduction to Arts & Bots Hardware Components Arts & Bots robot construction Activity
Day 2	Systems Engineering Introduction & Activity Introduction to Arts & Bots Programming Robot Programming Work Time & Demos
Day 3	Curriculum Discussion Overview of Robotics Activity Types Robotics Research Lab Tours
Day 4	Introduction to Evaluation and Assessment Tools Overview of Robotic Art Curriculum Project Work Time
Day 5	Robotics Research Lab Tours Curriculum Project Work Time
Day 6	Curriculum Presentations Hands-on Curriculum Demos

2011 Arts & Bots Pioneers Graduate Course

In the summer of 2011, the Arts & Bots program offered a six-day graduate level short-course called "Educational Robotics for the Classroom." During the course, eight enrolled teachers were given an immersive educational robotics experience with the newly updated Arts & Bots hardware and software, creating multiple Arts & Bots robots. We developed a lesson and provided instruction on the prototype software programming interface — the CREATE Lab Visual Programmer — and, following the conclusion of class each day, we made revisions to software as bugs were identified by the teachers. Each teacher developed Arts & Bots lesson plans for a variety of subjects, and these were used as example plans for later professional development. Additionally, through the six-day course we explored key concepts and skills required for successful classroom implementation. Through observation of the teachers and their feedback, we were able to further reduce the set of learning goals, making progress toward our goal for a single-day workshop for further dissemination of Arts & Bots.

2012 Professional Development Workshops

Duration	Topic
0:10	Introduction Arts & Bots
0:45	Introduction to Hardware Components
0:05	Example Robots and Class Projects
0:10	Break
0:50	Programming Overview with Mini-bot
1:20	Robot Construction Time
0:20	Robot Demonstrations
0:20	Debriefing Discussion

Table 4.3: Example schedule of 2012 four-hour PD Workshop

After both the residency and graduate course programs, participating teachers successfully implemented their developed curricula with students, demonstrating that Arts & Bots could be applied to classroom settings, and showcasing model curricula in a diverse set of disciplines. These teachers were asked to document their successes and model curricula via an online blog, where they uploaded lesson plans and contributed photos and anecdotes about their Arts & Bots experiences.[3] These examples continue to be both models and inspiration for future educators, and reduce the amount of time needed to develop curricula during structured professional development time.

Armed with a completely mature and commercially available hardware kit, significantly improved software environment,[4] and experience instructing teachers with diverse backgrounds and skill levels, we consolidated our training materials into a four-hour workshop that could be offered in a single evening or weekend session. The workshop includes the topics and activities that we found to be essential to teachers successfully implementing Arts & Bots, including: online curriculum examples, the Arts & Bots hardware components, the visual programming environment, building, programming, & sharing a complete robot, and a debriefing discussion.[5]

The demand for the course, and thus the potential for expansion, was directly related to course length and cost. We found that there

[3] Arts & Bots. Arts & Bots. Online Blog, 2017. URL `http://artsandbots.posthaven.com/`

[4] Jennifer Cross, Christopher Bartley, Emily Hamner, and Illah Nourbakhsh. A visual robot-programming environment for multidisciplinary education. In *2013 IEEE International Conference on Robotics and Automation (ICRA)*, pages 445–452. IEEE, 2013

[5] Emily Hamner and Jennifer Cross. Arts & Bots: Techniques for distributing a STEAM robotics program through K-12 classrooms. In *Proceedings of the Third IEEE Integrated STEM Education Conference, Princeton, NJ, USA*, 2013

was a much greater demand for and interest in single day Arts & Bots workshops than was expressed for the longer trainings, and because of decreased overhead involved in running shorter workshops, it was possible to offer the workshops roughly quarterly.

Between December 2011 and December 2014, we led fifteen workshops through the CREATE Lab at Carnegie Mellon University and the CREATE Lab Satellite at Marshall University in West Virginia. One hundred and ninety-nine educators received basic training on 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 Workshop Success

After running multiple workshops, we have identified several key aspects of a successful Arts & Bots training session.[6] As a robotics program, the teachers implementing Arts & Bots must be able to teach both hardware and software engineering. While we provide direct instruction on all the hardware components available in the kit, teachers must experience the challenges of constructing a robot from craft materials first-hand. Therefore, 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, no matter their prior engineering experience.

Through experimenting with several sequences of instruction,

[6] Emily Hamner and Jennifer Cross. Arts & Bots: Techniques for distributing a STEAM robotics program through K-12 classrooms. In *Proceedings of the Third IEEE Integrated STEM Education Conference, Princeton, NJ, USA*, 2013

we have found that it is important for the educators to inform their expectations by understanding the full capabilities and limitations of the Arts & Bots programming environment *before* building their robot. However, the programming environment interface requires that a physical robot be available to fully use the software. We address this chicken-and-egg problem by providing each participant with a "mini-bot" — a very basic, pre-constructed robot with a servo, a tri-color LED, and a light sensor. The mini-bots, shown in figure 4.1, are used by all the teachers while learning to navigate the programming environment. The teachers are then able to incorporate this programming knowledge during the design and construction of their own Arts & Bots robot, eliminating many common misconceptions that occur when programming is taught after robot construction.

Figure 4.1: Example mini-bot robot with a servo light sensor and tri-color LED..

As much as possible, we encourage educators to bring their own laptops. While the workshops would perhaps run more smoothly if they used pre-configured and tested computers, the experience of installing the software is valuable for participants if teachers truly plan to implement Arts & Bots in their schools. While the installation process is quick and easy for most participants, some school-managed laptops have settings that require additional debugging, and this gives educators first-hand experience working through these technical challenges under the guidance of experts. Identifying these IT barriers upfront allows teachers to find solutions before they interfere with class schedules, and simultaneously allows us to observe and identify school technology needs to inform software design improvements.

As previously mentioned, while the full-week graduate course fully prepared teachers, it required more time than schools could spare. The short four-hour workshop, by contrast provided decent technical preparation for many educators, but did not provide specific time for curricular planning or talent identification. Additionally, the short training time period did not accommodate educators working at a slower pace. Therefore, they may not feel completely confident in all aspects of both the hardware and software. Below we describe in detail the modifications we made to the four hour, 2012 PD model to address these issues.

Expanded Goals of the Math-Science Partnership Training

In 2013, one common theme of anecdotal feedback received from teachers was self-reported increased awareness of student talents in engineering and computer science domains.[7] We decided to refine and build on this finding, motivating the adaptation of the Arts & Bots program to help teachers identify student talent. This led to the Math-Science Partnership (MSP) stage of the program described in previous chapters. Therefore, we needed all teachers in the cohort to leave PD feeling ready and prepared to implement Arts & Bots in their classroom and to identify student talent.

[7] Jennifer Cross, Emily Hamner, Lauren Zito, and Illah Nourbakhsh. Engineering and computational thinking talent in middle school students: a framework for defining and recognizing student affinities. In *2016 IEEE Frontiers in Education Conference*. IEEE, 2016

The three main goals of MSP teacher training included:

1. They must leave PD feeling ready to instruct and support their students in the technical details of both hardware and software.
2. They must understand the student talents we hoped they would identify through the project.
3. They should leave with a concrete plan for instruction.

2013 Training Model

In 2013 teachers received PD based heavily on the 2012 Workshops, but with a few adaptations. For example, in our previous workshops, we introduced teachers to the hardware of the Hummingbird kit via a detailed, passive-learning lecture. This was followed by an introduction to the CREATE Lab Visual programmer, followed by directed practice with the programming software. We observed that in classrooms, teachers often did not have time to give a detailed introductory lecture on the hardware, and often used an online video tutorial to introduce the software. Since Arts & Bots is integrated into non-technical courses, detailed knowledge and understanding of the hardware components is not a priority learning goal of best-practice projects. Teachers, however, do need to have enough background to

Duration	Topic
Day 1	
0:20	Introduction Arts & Bots
2:30	Hands-on Hardware and Software Introduction Activity with Mini-bots
0:10	Example Robots and Class Projects
0:30	Lunch *optional construction time
1:00	Robot Construction Time
0:30	Robot Demonstrations & Debriefing
1:00	Curriculum Integration Examples
0:30	Curriculum Planning Work Time
Day 2	
0:20	Introduce Talent Identification
0:50	Talent Definitions Pair and Share Activity
0:35	Discussion on Identification and Talent Inventory Tool
0:45	Discussion of Supporting Talents
0:50	Research Project and Tools
0:30	Lunch *optional construction time
2:30	Curriculum Planning Work Time
0:10	Sharing and Wrap-up

Table 4.4: Schedule of 2013 two-day training workshop (13 hours)

feel confident teaching the material. We altered the structure of the hardware and software instruction, thus allowing teachers to practice using the hardware and software simultaneously during an active learning activity as suggested by Desimone [2009].[8] Teachers also hear about each component in terms of how it will be used by their students. Additional changes included time to work on curriculum, and training on student talent identification.

[8] Laura M Desimone. Improving impact studies of teachers' professional development: Toward better conceptualizations and measures. *Educational researcher*, 38(3):181–199, 2009

Figure 4.2: Member of the Arts & Bots team working with a teacher to use a minibot.

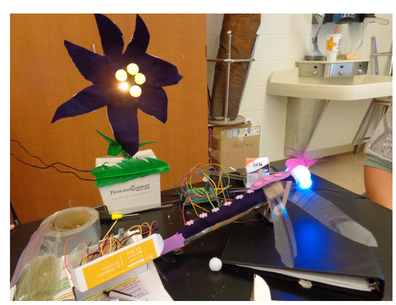

Figure 4.3: A dragonfly robot and a flower robot created by two teachers to interact with each other using sensors

Formative Evaluation of the 2013 Model

After each of their 2014-2015 school year implementations, teachers were surveyed and interviewed. Both survey and interview results suggest that teachers felt positively about their experiences implementing Arts & Bots in disciplinary classrooms. Results also suggested three areas in which PD could be further enhanced: building and programming, integrating robotics into class content, and talent identification. During this evaluation, 15 teachers completed the survey 18 times (three teachers completing the survey twice as they were asked to complete the survey following each implementation), and 14 teachers were interviewed.

On a scale of 1 to 5 (with 1 indicating "not at all prepared" and 5 indicating "extensively prepared") teachers reported feeling moderately prepared for building and programming robots (mean = 3.68

of 5, N=18), although the majority of teachers also felt they would benefit from additional training in this area. Specifically, these teachers called out building, programming, sensors, and sequencing as elements they would like to practice more, both to increase their own comfort, and to enable them to troubleshoot/answer questions from students. These teachers also emphasized the importance of allowing adequate time for practice, to increase familiarity with the equipment. As one teacher stated, "I would suggest to teachers who plan to do this that they take a Hummingbird Kit home, or spend time to make sure they build their own robot, and stretch themselves. It's hard to teach something that you don't know yourself." A few teachers with a more substantial technology background said they would like to learn more about using Scratch and other advanced languages with Arts & Bots, to be able to provide differentiated instruction to advanced students.

Teachers reported feeling moderately prepared to integrate robotics into their class content (mean = 3.5 of 5, N=18), but also felt they would benefit from additional training in this area. Some teachers suggested adding more explicit integration activities into the PD. They asked for specific help writing Arts & Bots lesson plans, thinking through how to implement Arts & Bots within their disciplines, and identifying content that would be amenable to Arts & Bots integration. Some teachers also asked that sample lessons be provided, so they would have models of how an integrated lesson might be constructed. Two teachers expressed interest in collaborating with other Arts & Bots teachers in their school to further increase their skills. One of these teachers expressed a specific interest in learning from others' pedagogy, commenting: "I always struggle with how much I need to directly involve myself in the student projects. I take an active role, but I'm not sure if I need to suggest more, guide more, intervene more...I'd like to assess my own implementation in comparison/contrast with some peers."

Talent identification was the third area in which teachers requested additional support. Teachers reported feeling somewhat less prepared to identify and cultivate student talent (mean = 3.18 of 5, N=18), and requested additional preparation with the talent inventories, more examples of talent behavior, and discussions of how to keep students invested in the program.

2015 Training Model

Following the 2014/2015 school year, we worked to improve the previous professional development format based on the feedback we received from teachers. Specific changes made as a result of teacher feedback are described below.

Table 4.5: Schedule of 2015 one-day training workshop (eight hours)

Duration	Topic
0:20	Introduction Arts & Bots and Robotics
0:50	Hands-on Hardware and Software Introduction Activity with Mini-bots
0:40	"Brown Bear Brown Bear" Sequence Task
0:40	"Parking Spot Helper" Sensor Task
0:10	Example Robots and Class Projects
1:20	Robot Construction Time
0:10	Robot Demonstrations & Debriefing
0:30	Lunch
0:20	Curricular Integration Tools Overview
1:00	Curriculum Planning Work Time
0:15	Curriculum Sharing Out Discussion
0:15	Clean-up Projects
0:15	Introduce Talent Identification
0:40	Talent Definitions Pair and Share Activity
0:35	Robot Taxonomy Talent Identification Activity

Technology Instruction

If teachers are expected to lead a technology project in their class, they must of course have adequate instruction in the technology themselves. We have used two strategies to establish this strong foundation in a time efficient manner: supporting synchronization, and sensor integration.

Supporting Synchronization

Students commonly encountered challenges integrating audio recordings into their programs. For example, students would recite a poem to be presented by their robot, create an audio recording, and include the audio clips in the program they wrote for the robot. However, getting the robot's actions to line up with the correct part of the recording required careful attention to timing in the program. Students struggled with this detail. We wanted to give teachers practice completing this same task, while offering potential classroom strategies for making it easier. We selected Martin and Carle's children's book, "Brown Bear, Brown Bear, What Do You See?"[9] as a simple story that lends itself well to the robotic components in our kit, namely tri-color LEDs. Teachers are tasked with recording the first several pages of the story and programming an LED to change colors to match the color of each animal mentioned in the story. We use this activity as the initial introduction to and practice for creating sequences. We follow a detailed step-by-step script, so that all technology concepts are covered. By focusing on a more difficult task that encompasses a basic programming requirement, we accomplish more in one professional development session because the simple part no longer requires extra time. Teachers receive a copy of the script, so that they may use it in their own classes if they choose.

[9] Bill Martin and Eric Carle. *Brown bear, brown bear, what do you see?*. Henry Holt and Co, New York, 1996

Sensor Integration

Another change in the order and focus of our PD was to introduce complex topics, such as sensors, much earlier. Previously, we had approached the training by beginning with the basics and progressing through more and more complex topics, ending with adding sensors into programmed sequences. Consequently, we observed that in many class implementations, students either used no sensors, or only superficially used sensors in their projects. For example, the start of the program may be triggered when a student places their hand near a distance sensor. This limited sensor use is in part due to the nature of class projects. They often tell a story (e.g. a scene from Romeo and Juliet) or demonstrate a concept via creation of a model (e.g. a model arm or a model of the Parthenon). Sensors are not required to do these tasks. However, we would like to ensure that teachers can support more integrated sensor use if desired, and that means scheduling more time or creating various tasks for teachers to familiarize themselves with the process. For example, talented students can be challenged to create an interactive robotic sculpture as a means of differentiated instruction within the Arts & Bots project.

Additionally, sensor integration has the ability to manipulate sequence and expression timing, allowing for more complex and refined programming. To address this issue, we introduced a new programming activity, the Parking Assistant Challenge. Teachers must make a warning light to help people park their cars. They program an LED light to go from off, to green, to yellow, to red as the distance sensor detects closer and closer objects. As an introductory programming environment, the CREATE Lab Visual Programmer, as described in chapter 6, does not have many complex programming structures.[10] This task requires the programmer to practice with one of the more complex structures in the programming environment and challenges them to think innovatively and creatively.

[10] Jennifer Cross, Christopher Bartley, Emily Hamner, and Illah Nourbakhsh. A visual robot-programming environment for multidisciplinary education. In *2013 IEEE International Conference on Robotics and Automation (ICRA)*, pages 445–452. IEEE, 2013

These activities were developed to address some pitfalls in a constructivist-oriented Arts & Bots project. By teaching through scaffolded activities, and encouraging teachers to use the activities in the classroom, we not only teach them the skills required to implement a successful Arts & Bots project, but also model the scaffolding we would like them to use in their classrooms. Additional worksheets detailing step-by-step instructions for troubleshooting and concept diagrams for avoiding common misconceptions were also made available.

Recognizing Student Talents

The most recently developed piece of the Arts & Bots program was training for teachers to help them recognize student talents in computational thinking and engineering design. Computational thinking (CT) is a way of solving problems using methods from computing and computer science such as algorithms and logic.[11] CT exercises students' skills in handling complexity, ambiguity, and open-ended problems; persistence in working with difficult problems; and communicating and working with others to achieve a common goal.[12] Engineering design (ED) is the process of developing a concrete solution for an ill-defined problem within tech-

[11] Jeannette M Wing. Computational thinking. *Communications of the ACM*, 49(3):33–35, March 2006; and International Society for Technology in Education and Computer Science Teachers Association. Computational thinking: leadership toolkit, 2011. URL `http://csta.acm.org/Curriculum/sub/CurrFiles/471.11CTLeadershiptToolkit-SP-vF.pdf`

[12] International Society for Technology in Education and Computer Science Teachers Association. Computational thinking: leadership toolkit, 2011. URL `http://csta.acm.org/Curriculum/sub/CurrFiles/471.11CTLeadershiptToolkit-SP-vF.pdf`

nical feasibility constraints.[13] Design develops students' skills in real world problem solving, synthesizing new thoughts and concepts, and communicating mental imagery through graphical representations.[14] Because our target educators did not primarily come from a technology background, a goal of the PD was to introduce them to these concepts.

[13] Nigel Cross. Designerly ways of knowing. *Design studies*, 3(4):221–227, 1982; and Tim Brown. Design thinking. *Harvard Business Review*, pages 84–95, June 2008

[14] Nigel Cross. Designerly ways of knowing. *Design studies*, 3(4):221–227, 1982

We break CT and ED talents down into several categories, described in detail in chapter 7 and in Cross et al. [2016].[15] We provided teachers with several resources to guide them: detailed talent component definitions, practical examples of how the individual components of talent could be expressed by students, and summary talent definitions for quick reference. Because of the wide breadth of material, we approached this portion of the PD with a pair-and-share activity. Teachers worked in pairs or small groups to review the printed material and share their understanding of the various components with the larger group. We provided clarification or additional detail throughout the "share" portion of the discussion. We provided a variety of support materials to teachers including a 14-page student design notebook. The design notebook, provided in Appendix H: Student Design Notebook with NGSS Reference, walks students through the steps in the design process and serves as a scaffold for engineering design.

[15] Jennifer Cross, Emily Hamner, Lauren Zito, and Illah Nourbakhsh. Engineering and computational thinking talent in middle school students: a framework for defining and recognizing student affinities. In *2016 IEEE Frontiers in Education Conference*. IEEE, 2016

As a result of teacher feedback in initial PD rounds indicating that they still desired more training on talent identification, we included, in later sessions, a discussion centered around photos of example student robots. The photos demonstrated various levels of talent expression, and provided an opportunity to critique sample student work from the viewpoint of engineering design.

Teacher-to-Teacher Collaboration

Across both districts participating in the project, we frequently saw teachers co-teaching Arts & Bots projects in pairs. This allowed more experienced or more confident teachers to support less confident teachers while they developed their technology skills.

Teachers also benefited from the opportunity to discuss curricular integration ideas, as well as practical project implementation considerations (ex: time management, computer set up, equipment management) with their peers. The PD served as a space for this collaboration to take place.

One way to enhance these collaborations is by engaging teams or cohorts of teachers together. We found teachers to be most likely to follow through on projects if a cohort from a school all attend the same workshop and make plans together. In contrast, a problem we saw with the older, half-day, public workshop model was that a single teacher or educator from a school or organization would come, but not have a network of local peers for support. This caused that teacher to have more implementation hurdles to face alone. It was helpful if teams spanned the spectrum of school infrastructure such as teachers, technical specialists, principals, and curriculum directors. The more buy in and availability of support at the school the better.

Teachers did not always have the opportunity to work with more experienced educators in person. For this reason, we created a teacher "tip sheet" with an ever-evolving list of recommendations for implementation tips from the project teachers and researchers to help share ideas between organizations. Teacher provided tips were collected from teacher interviews, surveys, and class observations. The tip sheet covered topics including: choosing a project topic and designing a project, setting up classrooms, tools and equipment considerations, making student teams, running research, and debugging hardware and software issues. This sheet is provided in Appendix I: Teacher Tip Sheet.

In talking with teachers about the other Arts & Bots projects in the school, we found that even in a small school, teachers have very limited opportunities for communicating with their peers about classes and students. In many schools, the only open discussion time that teachers have is during their 30 minute lunch break, when they get to talk with the teachers who have the same lunchtime. As we talked with teachers, we observed that ideas and solutions that other teachers had developed were of great interest and clearly were not being naturally shared across the school. This finding was consistent with other research in the field of Professional Development which has highlighted the importance of fostering communication among teachers and the collective participation of groups from the same schools for providing effective and sustained improvements.[16] In an interview, an 8th Grade English teacher expressed a need for more inter-teacher curricular collaboration time, saying: "So if we had more time afterwards, ... I think it would be beneficial to also be talking with other English teachers, other language arts teachers, to kind of bounce ideas off of each other, especially other teachers that have done Arts & Bots." By bringing teachers together for initial PD, as well as follow-up sessions, and integrating community building exercises and discussions into PD, teachers had the time to share and reflect with their peers.

[16] Michael S Garet, Andrew C Porter, Laura Desimone, Beatrice F Birman, and Kwang Suk Yoon. What makes professional development effective? results from a national sample of teachers. *American educational research journal*, 38(4):915–945, 2001

Curricular Plan

A key goal of our PD is that teachers leave with a concrete plan for implementation. Our earlier workshop focused on hardware and software training, with inspiration for curricular integration through example projects from pilot teachers. In the new PD schedule we wanted to give teachers dedicated time to focus on their curriculum plans. Teachers frequently do not have a lot of time to do planning during the regular school week. Giving them time to plan in the workshop supported by peers and experts helps them develop concepts faster and receive feedback.

We combined our older workshop with materials developed by our partners from the school of education at Marshall University. Activities included brainstorming about the content areas students struggle with and sharing ideas with peers to get feedback on their lesson plans. These activities are designed to help teachers identify topics that would benefit from the addition of an Arts & Bots activity.

Teachers have noted the difficulty inherent in determining the balance between disciplinary and technical goals in the classroom, and between constructivist and direct instruction approaches. Some teachers emphasized the technology goals. Rather than providing specific integration tasks appropriate to their content area, they allowed students to create any robotic structure and commited a great deal of class time to direct instruction on technology skills and knowledge goals. Other teachers took the opposite, more constructivist, approach, spending no more than a few minutes providing direct instruction on the hardware and showing the software videos when necessary, and then focused class time on the integration of content goals with student projects. This approach may be successful with some advanced students (or students with existing technology skills), but might be unsuitable, unsuccessful, or frustrating for complete novices (who are a target demographic for the program). Ideally, there would be a balance between these constructivist approaches and direct instruction. The constructivist approach allows for more exploration time, fostering deep and engaging hands-on interactions with the hardware and software. However, the lack of strict structure could consume class time and cause students to develop misconceptions about the equipment and their abilities.

We recognize that technology and engineering design are not the teachers' fields of expertise. In order to help teachers provide a suitable amount of direct instruction in these areas, we provided tools for scaffolding student work such as a student design packet and related worksheets. We encouraged teachers to integrate these tools into their curricular plans.

Another factor in selecting a project topic was equipment scheduling. Where the project falls within the semester affects the class topic with respect to continuity of ideas, concepts, and class themes. Sharing equipment across teachers is a nice way to reduce costs, but care must be taken to provide adequate schedule management. We found that if teachers within the district plan to share equipment, it is essential that all teachers can agree on a schedule during the curriculum planning phase. This is especially critical in programs like Arts & Bots, where the technology can be adapted to complement the disciplinary topic being studied. When teachers were uncertain when they would have access to equipment, either due to delays in equipment acquisition, or because of an uncertain sharing schedule, they had a very hard time developing their curriculum plans.

In other instances, we found that project planning depends upon when a school and teacher could actually acquire the kit. That is, rather than determining which topic would work best for a project within the scope of a year, teachers considered how it would best integrate during the 1-3 months their school will have their turn with equipment.

From both a research and instruction perspective, it is immensely helpful for the teachers to be able to schedule their Arts & Bots implementations with respect to their year long or semester long plans. If the project was scheduled with intention, the class content was more coherent.[17] As researchers, we were notified when to follow up, and ensured that the proper research documents and procedures were in place. Lastly, administrators could more easily organize materials and ensure that all other resources are prepared in advance.

[17] Debra Bernstein, Karen Mutch-Jones, Emily Hamner, and Jennifer Cross. Robots and Romeo and Juliet: Studying teacher integration of robotics into middle school curricula. In *International Conference of the American Educational Research Association*, 2016

Additional considerations

In addition to the basic knowledge needed to teach a class and an appropriate curriculum to teach, there are several other considerations that can lead to either a challenging or successful implementation. We describe some considerations that arose through the piloting process in the hope that others implementing technology pilots can benefit.

Some considerations stem from the scope with which multiple teachers have implemented Arts & Bots at their school districts. In one district, students often entered a class having completed an Arts & Bots project three or four times. If a teacher is new to Arts & Bots, or if this is their first implementation, they need to address and prepare for the fact that students, through their increased familiarity, may ask questions beyond the teacher's experience and skill. Schools have coped with this imbalance in difference ways. For instance, one district initiated the program using a gifted-support teacher as the primary Arts & Bots catalyst. She accompanies other teachers during their implementations, providing insight and guidance. A 7th Grade English teacher expressed her gratitude in a teacher interview saying, "Sometimes I just feel like I don't know what I'm supposed to say to them. But I told them, too. I was like, I just made this robot for the first time ever. You guys have probably done this more than me. So I will help you in any way I can, but I'm probably not going to know all your answers. But luckily, we have [another teacher] and she's going to help us." This teacher is not alone in her feeling of relief. A 6th Grade Social Studies teacher expressed a similar feeling: "[...] the first year, [another teacher] was down here, and helped. That was really nice. And probably imperative, really, on my part, because I knew some, but didn't feel as comfortable with it."

An additional factor in holding a successful PD is scheduling of the PD itself. We found that using school in-service days only worked if teachers could be guaranteed not to have other obligations. Sometimes the district or state would mandate certain training requirements that teachers must fulfill on these days — sometimes at the last minute — leaving teachers without availability to train. Multiple short after-school sessions were another option we experimented with. This worked if the group of teachers was small enough such that schedules could be coordinated. However, many teachers organize clubs or sports, so scheduling became a challenge as the size of the group grew. Setting aside a day or two in the weeks leading up to the start of school in the fall was a fairly successful strategy. Dates closer to the start of school were easier for teachers to attend, because they were finished with vacations and other obligations as they prepared to return to school. Scheduling these days in advance improved attendance, but could be a challenge when school schedules were not yet fixed. Providing teacher incentives (such as PD credit from the state or district, or the ability to skip other PD days) for PD outside of the school-day helped attendance. Days when the school could provide substitutes, thus allowing PD to take place during the normal school hours, were very successful. Building funds into the research grant budget to allow for adequate substitutes can make this type of PD possible.

Despite best efforts, there were times when a teacher could not attend a scheduled professional development session. In these cases, a single-day, one-on-one session was scheduled instead. During these sessions, the researcher would review the same materials and the teacher would participate in the same software and hardware practice activities as the other two-day sessions. The individualized attention allowed for a faster paced professional development, while still thoroughly covering the necessities. However, teachers who participated in the one-on-one training session do not experience the additional benefit of teacher-teacher collaboration. To account for this, we encouraged teachers who received individual PD to collaborate with more experienced Arts & Bots teachers at their schools. Several teachers, during interviews, mentioned that the help of a more experienced teacher was a contributing factor to the success of their implementation.

Several teachers have implemented more than one project during our multi-year research effort. Because of their prolonged involvement, they have attended multiple PD sessions. Often, these sessions act as a refresher; teachers are reminded of the project goals, talent definitions, and the software and hardware capabilities. If a PD session is primarily repeat teachers, we often place a greater emphasis on talent identification, spending time reviewing past projects and discussing how to assess them.

Additionally, teachers use these repeat sessions as a time to refresh their perspective on their own project and methods. An 8th grade English teacher commented, "I have such tunnel vision in my project myself, that I think of, this is what they look like. But when I went to a workshop, I saw different, like robotics sculptures and things made. It's like, I never would have thought. ... how are other people using it? And maybe that would even adjust how I would change mine. Like oh, okay. We've done this a few times, but maybe we could try representing it in a different way." The teacher-to-teacher communication time, as well as, the discussion of past projects expands one's thinking on ones own projects.

Outside of PD sessions, teachers express the importance and benefits of practice and repeat exposure. Even teachers that have only attended one professional development session have expressed wanting more review time. During a teacher interview, a 7th grade English teacher noted the importance of revisiting these techniques and technology saying, "I would like to just make my own [robot] again, to be honest, or just, maybe not make a, like the whole box, but the programming of it. Like the creative part, I could probably be fine with, but the actual programming, that definitely wouldn't hurt to have like a refresher...I think it's just me doing it more than once. I only really did it once, and so I forget, and then eventually I'll get it the more I do it, but I'm one of those people who has to like keep doing it, or I'll forget, like my grandma with a computer, or the mouse. You know what I mean? She has to do it every day."

Methods

An evaluation of teacher implementation was conducted during the 2014-2015 school year. As part of this broader study, we collected data about professional development from 15 participating teachers, from a variety of disciplinary backgrounds, via interviews and surveys designed to capture teachers' reflections about their experience with Arts & Bots professional development, school-based support, and teachers sense of efficacy. Table 4.6 provides further detail about instrumentation. Baseline survey data were collected prior to teachers' first PD experience, log data were collected multiple times during each teacher's implementation, and final survey and interview data were collected at the conclusion of each teacher's Arts & Bots implementation.

Results

Overall, teachers saw Arts & Bots as beneficial to their teaching, with 100% of this cohort indicating that it enhanced their teaching. As one teacher described the experience "[...] creating something from scratch to move and demonstrate understanding...was a unique

Instrument	Data Collected
Baseline survey	Teacher demographics Sense of Efficacy (2 subscales)
Implementation Log	Classroom characteristics Teacher use of Arts and Bots, materials/technology Teacher perceptions of implementation successes and challenges Teacher perceptions of student work and talent
Final Survey	Teacher Perceptions of contributions of Arts & Bots to their instruction and to student learning — disciplinary, technology, and talent goals Retrospective teacher perception of contributions of PD Sense of Efficacy (same subscale items, as baseline)
Interview	Probes of teacher response in logs and on our final survey (including explicit questions about PD benefits and ongoing needs)
Observations	Level and type of robot integration with disciplinary activities Teacher interactions with students

Table 4.6: Instrumentation

opportunity. I don't think I would have been able to do what I did with anything else but the robots."[18]

We simultaneously collected longitudinal data of teacher self-efficacy to understand the extent to which teachers felt comfortable with, and were able to persist in the face of, the challenges associated with integrating a robotics curriculum into core middle school subjects. Such characteristics are indicative of a strong sense of efficacy.[19] Teacher efficacy data was collected using a modified version of the Math Teaching Efficacy Beliefs Inventory (MTEBI). The MTEBI is a 21-item scale designed to measure mathematics teaching efficacy beliefs).[20] These items are divided into two subscales: Personal Mathematics Teaching Efficacy (PMTE) and Mathematics Teaching Outcome Expectancy (MTOE). Previous research conducted by Enochs et al. [2000] suggests that, of the 21 items, 13 items contribute to the measurement of PMTE and 8 items load onto MTOE. We modified the PMTE items by replacing the word mathematics with robotics and the MTOE items by replacing the word mathematics with computer science/technology. For clarity, we will continue to refer to the subscales using the same acronyms (PMTE and MTOE) as the instrument authors. Self-efficacy data were collected prior to PD, and after classroom implementation. Some teachers have remained with the project for several years and, thus, completed a post-survey

[18] Debra Bernstein, Karen Mutch-Jones, Emily Hamner, and Jennifer Cross. Robots and Romeo and Juliet: Studying teacher integration of robotics into middle school curricula. In *International Conference of the American Educational Research Association*, 2016

[19] Craig D Jerald. Believing and achieving. issue brief. *Center for Comprehensive School Reform and Improvement*, 2007; and Nancy Protheroe. Teacher efficacy: What is it and does it matter?. *Principal*, 87(5):42–45, 2008

[20] Larry G Enochs, Phillip L Smith, and DeAnn Huinker. Establishing factorial validity of the mathematics teaching efficacy beliefs instrument. *School Science and Mathematics*, 100(4):194–202, 2000

multiple times. For consistency, we used post-scores from the surveys completed after each teacher's final implementation.

Analyses for the PMTE subscale showed a significant effect of time on pre to post scores, (paired t-test, $N=14$, $t = 2.234$, $p = .042$). For MTOE subscale there was no significant effect of time on scores. Given the small number of teachers and the exploratory nature of this project, we do not make any efficacy claims beyond what we see in this teacher group. However, for this cohort, we see that participating teachers' sense of personal teaching efficacy (their confidence in their own teaching abilities) grew while participating in the project and employing Arts & Bots within their classes. We acknowledge there may have been other things that occurred during this time period that contributed to this growth, and we are now investigating how the number of follow-up professional development activities, support within a school, and the number and type of implementations influence teachers' sense of efficacy. We also note that participants' sense of their teaching outcomes expectancy did not change.

Summary

Teacher training integrates experience with the robotics kit components, a programming interface, the engineering design process, and student computer science and engineering talent recognition. Our goal for PD is to prepare non-technical teachers to implement Arts & Bots in a meaningful way within their curriculum and thus be able to identify student engineering and computing talents. Based on teacher feedback, we modified the PD to better prepare teachers for the more challenging aspects of Arts & Bots, such as complete sensor integration and complex programming structures. Key features of our revised PD include: new hands-on activities focused on the most challenging aspects of Arts & Bots technology, such as audio integration and sensor use; training for teachers on engineering design and computational thinking, exploring how student talents in these areas might be expressed through Arts & Bots; emphasis on teacher-to-teacher collaboration and discussion time; and dedicated time for curriculum development and to plan for their implementation.

Our revised PD as described above has much in common with the PD recommendations of Desimone [2009][21] and Martin et al. [2010].[22] The PD is focused on content and connected to teacher practice. We model instruction, having teachers participate in active learning activities utilizing the technology they will actually be teaching. As much as possible, we encourage collective participation and community building within PD.

[21] Laura M Desimone. Improving impact studies of teachers' professional development: Toward better conceptualizations and measures. *Educational researcher*, 38(3):181–199, 2009

[22] Wendy Martin, Scott Strother, Monica Beglau, Lauren Bates, Timothy Reitzes, and Katherine McMillan Culp. Connecting instructional technology professional development to teacher and student outcomes. *Journal of Research on Technology in Education*, 43 (1):53–74, 2010

Future Directions

Several teachers expressed difficulty in developing assessment methods for the robotics component of their implementation as well as the implementations at large. This may be because many teachers in traditional disciplines, such as math, science, or socials studies, are used to teaching concepts that have singular correct facts, common defining features of success, and skills which follow explicit steps. In contrast, in computer science, design, or engineering, there are often many excellent solutions, methods, and possible paths for students. The process of designing goals, assessments, and rubrics for encouraging these open-ended experiences might be unfamiliar to many K-12 teachers. While a few teachers who have completed several implementations do have a rubric with which they assess student work, a standard or universal rubric that can be altered to fit a variety of teacher implementations does not exist. In the future, we can add sections in the PD session to discuss rubrics, providing successful and/or useful examples. Additionally, teachers requested a greater emphasis or additional time on curriculum development, which we will consider when creating the schedules for future sessions.

Many teachers discussed the importance of their students developing "soft" skills, sometimes classified as 21st Century Skills,[23] as one of their primary motivators for engaging in the Arts & Bots project. Time-management and teamwork skills were particularly noted by teachers. Students similarly expressed that they valued

[23] Partnership for 21st Century Learning (P21). Framework for 21st century learning. Online, 2007. URL `http://www.p21.org/storage/documents/docs/P21_framework_0116.pdf`

teamwork aspects of the project when responding to the survey question, "What was the best thing that you learned?" This common theme was unexpectedly prominent and highlighted an aspect of the project that was neither part of the formal program goals, nor addressed in the current model of professional development. As many of our teachers come from disciplines where large scale team design projects are less common, not all teachers implemented best practices for supporting the development of good teamwork and time management skills. Thus, in the future, we intend to develop new instructional goals around the development of these skills, as well as curricular materials and the associated teacher training activities.

Other teacher-training research programs have identified the importance of building teacher communities through collective participation.[24] Through the development of our training model, our observations perfectly matched these conclusions. We found that teachers benefit most when they attend the training sessions in same-school teams and are given opportunities to collaborate with their peers, learn from the experience of their peers, and develop a peer community to provide feedback. These aspects are of critical importance, and we are considering ways to further support these community building efforts with our professional development workshop, our program at schools, and beyond the Arts & Bots program with our school district partners. We have seen some of our participating teachers pushing this progress by organizing and leading their own versions of our workshops with other teachers at their schools or districts, as well as colleagues from other local districts.

[24] Laura M Desimone. Improving impact studies of teachers' professional development: Toward better conceptualizations and measures. *Educational researcher*, 38(3):181–199, 2009; and Wendy Martin, Scott Strother, Monica Beglau, Lauren Bates, Timothy Reitzes, and Katherine McMillan Culp. Connecting instructional technology professional development to teacher and student outcomes. *Journal of Research on Technology in Education*, 43 (1):53–74, 2010

5

Implementing Creative Robotics in the Classroom

The work presented in this chapter builds upon our in-school pilot program. Through the Arts & Bots project, 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[1] combined with craft or recycled materials to construct their robots. They program the robots using a visual programming language (see chapter 6) through which they first create "expressions," saved configurations of outputs, and then combine these expressions into "sequences," much like storyboard frames are combined.

Portions of this chapter first appeared in:

Hamner, E., Zito, L., Cross, J., Slezak, B., Mellon, S., Harapko, H., & Welter, M. (2016). Utilizing engineering to teach non-technical disciplines: case studies of robotics within middle school English and health classes. In 2016 IEEE Frontiers in Education Conference (FIE).

[1] BirdBrain Technologies. Hummingbird Robotics Kit. Online, 2017. URL `http://hummingbirdkit.com`

In this chapter, we provide two case studies of such projects; describe how the projects were refined and developed by teachers through sequential implementations, and discuss how instruction developed student technological fluency, collaboration, and understanding of class content.

The first case study presented is an integration of Arts & Bots into seventh and eighth grade English Language Arts (ELA) where students built robotic sculptures that represent a poem or scene in a play. The second case study presented shows students building models of human joints and limbs in order to study complementary muscle motion in seventh grade Health and Physical Education

(HPE). These two case studies examine projects instances where the robotics project: (a) is linked to a disciplinary 'big idea,' (b) is designed to support the development of key concepts, and (c) includes classroom activities, materials and evaluation that reinforce learning goals in the integrated discipline. This style of integration is contrasted with two other styles of robotics project integration — *exposure to disciplinary content through robotics* without integration and exposure to robotics with *no clear connections to disciplinary goals*, described by Bernstein et al. [2016].[2] 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.

[2] Debra Bernstein, Karen Mutch-Jones, Emily Hamner, and Jennifer Cross. Robots and Romeo and Juliet: Studying teacher integration of robotics into middle school curricula. In *International Conference of the American Educational Research Association*, 2016

Development of Case Studies

Both case studies took place at a small, public suburban junior-senior high school (46.7% free and reduced lunch) located outside of Pittsburgh, Pennsylvania. The school serves approximately 460 students in grades 7 through 12 (about 80 students per grade level). The first 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. The second case study is a record of six HPE robotics projects completed between 2014 and 2016.[3] These projects were completed over three school years by two teachers and 89 seventh grade students.

[3] Student survey and exit ticket data is only analyzed for five classes due to ongoing data processing at the time of writing.

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 data analysis presented in this chapter focuses on student and teacher experiences in the ELA and HPE classes described in this case study. Teacher interviews were conducted by external evaluators — each with a doctorate in cognitive psychology or education — before implementation, and during or after implementations. Student survey data were 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 seven 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.

Figure 5.1: A poetry robot representing the poem "The Pasture" by Robert Frost that had trees and other components actuated by servo motors and LED lighting, which coordinated with a recorded reading of the poem.

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 containing figurative language and symbolic imagery. Middle school students encountering Shakespeare or other poetry 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. 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.[4]

[4] Michael J. Prince and Richard M. Felder. Inductive teaching and learning methods: definitions, comparisons, and research bases. *Journal of Engineering Education*, 95(2):123–138, 2006; and Julie E. Mills and David F. Treagust. Engineering education - is problem-based or project-based learning the answer. *Australasian Journal of Engineering Education*, 3(2):2–16, 2003

The Arts & Bots robotics project presented in this case study is designed to support ELA learning objectives aligned with literary analysis. The principal goal of the project is for the students to carefully decompose the literary elements of an assigned text: either a poem in seventh grade (figure 5.1), or a passage from Romeo and Juliet in eighth grade (figure 5.2). Students analyze, interpret, and design a sculptural, robotic representation of a poem. The final 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 multiple 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.

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 robotic representations of them. Poems for the seventh grade classes were chosen by the teacher based on the use of figurative language and symbolism that best represents their seventh grade curricular goals. Meanwhile, after reading Shakespeare's Romeo and Juliet, eighth grade students are assigned a monologue, sonnet, or soliloquy. Their goal is again to dissect and explore its meaning — significance of its symbolism and word choice. In both grades, the students then communicate their analysis by creating a visual representation of the text with the use of Hummingbird Robotics Kits and craft materials, though the eighth grades were given more rigorous requirements than those for the seventh grade implementation.

Class schedule

The timeline of this project involves five days of block scheduling (ten 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 placed into groups of three, and provided with a copy of their literary work and a planning document. The planning document asks 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. One student creates audio recordings using Audacity,[5] 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 used to tweak, refine and present final projects to peers. This day is also time for 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 eight class periods or four days of double block classes.

Student Exit Ticket responses support that students experiences roughly follow the class schedule, provided 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

[5] Audacity. Online, 2016. URL `http://www.audacityteam.org`

Figure 5.2: Three robots created by eight graders representing passages from Romeo and Juliet. One robot [top] plays recorded audio and displays the dual between Tybalt and Mercuito — shown as colored pipe cleaner figures — which are actuated by servos and lit by LEDs. The next robot [center] plays recorded audio and displays the dance where Romeo and Juliet meet. Figures are moved by servos. LED lights, along the top, indicate which character is speaking the lines of record audio. The last example [bottom] plays recorded audio and displays the dual between Tybalt and Mercuito. They are each represented on motor-driven rotating disks in three poses: standing, fighting with swords, and dead [shown]. As the recorded dialog plays, the spinning platforms show the progression of each character's status.

for the day, did so on Day 1 of the implementation, with percentages decreasing in the later days of the implementation. A large amount of "Designing and Planning" task reports (35.1%) 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.

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.

1. Planning - The planning document is assessed for writing conventions, as well as selection comprehension and literary analysis.

2. Recording - 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.

3. Teamwork - During collaborative activities, teachers capture formative assessment of the students' ability to clearly express their ideas. (ELA Standard - CC.1.5.8.A).

4. Programming - 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 Mercuito and Tybalt's actions during the Act III fight scene in Romeo and Juliet (shown in figure 5.2 [bottom]).

5. Hardware - As a technological skills requirement, the rubric indicates a minimum number of robotic parts as well as the expectation that a sensor is used for starting "the show."

6. Arts - The "arts" in the robot 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.

7. Presentation - 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.

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 shifted toward a support role.

In the five school years since the initial Arts & Bots implementation, 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 caused by working in the locked-down computing environment of a school district. The projects in both grade levels initially covered similar poetry content. The ELA classes grew into two independent projects where (as described above), the eighth grade classes focus on more difficult Shakespeare content, including more challenging vocabulary and unfamiliar sentence structure.

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, where the students used a pre-constructed robot to learn the programming skills needed 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 now able to spend less instructional time teaching programming and robotics, and more time on cultivating STEM talent in their content areas.

Student misconceptions in early implementations led teachers to institute 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 to 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 planning document, the students provide a line of text, explain the meaning of the text in their own words, plan visual elements to symbolize the text, and consider how to incorporate robotics into those elements. 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. Though the projects differ in requirements and final product, a familiarity 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 meanwhile 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 students understood how 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 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.

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 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 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 was a goal of the two HPE teachers involved to thoughtfully design a project that allowed biomechanics to take center stage, while more subtly immersing students in a culture that promotes the deeper values of STEM learning. Throughout the past three years, the project has gone through several iterations, continually 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 is to have students create biomechanically correct and working joints using Hummingbird robotics kits and 95% recycled materials (figure 5.3). The traditional method of teaching biomechanics was considered, by the HPE department, to be a rather dry and unexciting lesson for middle school students. In the past, to understand this concept, students were, at best, able to view working diagrams, watch videos, or try to feel their own muscles working in complementary motions. However,

Figure 5.3: Two biomimetic robots from a seventh grade health and physical education class, a knee (left) and an arm (right)

with the infusion of Arts & Bots into the non-technical setting of HPE class, students are able to create a product that demonstrates a much deeper understanding of complimentary motion.

Project description

The students work in small teams of two to three members to research, prototype, program, build and present their working joint to the class. The teams are allowed to choose one of three 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. Students must draw, get feedback on, and receive approval of a schematic plan of their joint before they are allowed to begin 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.

Class schedule

The students are given approximately 10 class periods (45 minutes per class), two of which are used to complete research surveys. The remaining eight are used to research, design, build, and present the entire project.

During the first class period, students are introduced to the project parameters, and given a brief explanation of biomechanics. On the second and third days, students research their 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. Much of the "Designing and Planning" task reports, 19.9% and 16.2%, 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. Students concluded their projects with more focus on programming and building, 17.8% of all "Programming" task reports and 17.3% of "Building or Working with Robot Parts" task reports occurred on Day 7 of the implementations. The last day, Day 8, was dedicated to presentations.

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.

1. Biomechanics - 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 that moves the forearm up and down, would not demonstrate learning in this area.

2. Programming - In this category, the students must demonstrate a complexity of programming that allows for accurate movement of their joint.

3. Hardware - This category requires students to successfully build a working joint free of catastrophic failures that also meets a minimum requirement of robotics parts in use.

4. Arts - 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 deliverable with a clear purpose communicated.

Using these four categories as a framework for the projects allows the students to take non-linear paths to learning the content of biomechanics. Ultimately, through this assessment method, the teachers can see how students have either deepened their mastery of biomechanics and STEM, or can be identified as in need of more attention.

Curriculum development and refinement

To fully understand how this project has changed over the past three years, it is important to understand the teaching dynamic for this specific case study. In this instance, this project was co-taught between a HPE teacher that was extremely comfortable with technology integration and another HPE teacher that was 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-technology-inclined teacher was able to take over more responsibily solving technical issues. With this shift occurred, the technology-inclined teacher was able to explore ways to focus the project 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, understanding Arts & Bots technology has become less focal for the teachers, and much more time is spent around improving the teaching strategies that accompany the project. For example, the planning schematic that must be approved before building has become a staple of the project. The teachers have learned the importance of student planning — to save time, energy and unnecessary failure — ultimately producing better projects. We equate this 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. Over the past three years through the self-reflection exercises this research project demands, the teachers have consistently revised the project to better align with the HPE learning taking place.

Case Study Discussion

The two case studies described are based on 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.

Differences

The two case studies 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. By the end of a ten-class period project, the HPE students spent an additional 25 to 50 minutes of class time on set-up and clean-up compared to the ELA classes. This leads to project where teachers must commit additional time in their schedules to Arts & Bots or must lower their expectations the final deliverables.

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. The correlation between content and Arts & Bot goals is a hallmark of well-integrated projects.

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 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 connection with their class content. As teachers developed an understanding of the technology, they are able to help students complete more complex projects.

Finally, both projects allow students to be exposed to 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.

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 better connect their projects to the ELA and HPE subject content through explicit design. 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.

Conclusions

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 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 despite students being 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 illustrate their robot design and its 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, to promote student learning outcomes, that integrated robotics projects include grading rubrics that balance technology requirements and disciplinary goals.

6

Developing a Programming Environment for Creative Robotics

A primary contribution of our work was the redesign and development of the Arts & Bots programming environment, the CREATE Lab Visual Programmer. Our observations of teachers using the visual programmer in professional development programs and classrooms, and our collection of feedback from teachers and students made it clear that the software initially created for Robot Diaries suffered from usability issues and misaligned goals that interfered with its integration into in-school class activities. We worked to redefine the goals of the programming environment to match the needs of teachers, and redesigned the CREATE Lab Visual Programmer to achieve those goals as part of the Arts & Bots Pioneers program.[1]

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Cross, J., Bartley, C., Hamner, E., & Nourbakhsh, I. (2013). A visual robot-programming environment for multidisciplinary education. In 2013 IEEE International Conference on Robotics and Automation (ICRA), (pp. 445-452).

[1] Jennifer Cross, Christopher Bartley, Emily Hamner, and Illah Nourbakhsh. A visual robot-programming environment for multidisciplinary education. In *2013 IEEE International Conference on Robotics and Automation (ICRA)*, pages 445–452. IEEE, 2013

Programming Environment Goals

In order for teachers to be able to implement Arts & Bots in their classrooms, we needed to provide an appropriate software environment to facilitate programming of robot behaviors and interactions, as well as meet specific goals that align with the overall purpose and needs of the Art & Bots program:

1. *Computational Thinking* - To support the development of student technological fluency, the Arts & Bots programming environment should support the acquisition of computational thinking skills. To

do this, the programming environment should permit the exploration of common computer science practices, such as creating reusable code, and understanding basic logical structures (e.g., *if-else* conditionals).

2. *Classroom Compatibility* - Arts & Bots must support the goals of the educator implementing the system in a multidisciplinary fashion. In the ELA class studying poetry, Arts & Bots must encourage deeper student engagement with poetry. In the HPE class studying muscles, Arts & Bots must help students refine their understanding of the mechanics of the musculoskeletal system. This means that, while the ideal programming environment should have the flexibility to be adapted for different types of projects, it should not be specialized for any singular course topic.

3. *Low Barrier to Entry* - Another crucial component of adaptability is the time needed for students to learn to create their first program. Reducing the learning curve minimizes time students spend away from the course topic, and allows teachers unfamiliar with computer programming to instruct students with confidence. Lower barriers also promote technological fluency by supporting students' gradual acquisition of technological knowledge, without damaging their confidence by straining their developing competency.

4. *Compelling Behaviors* - While it is important to simplify the complexity of learning to program, it is also critical that the programming environment not over-simplify the capabilities of the robots to the degree that students can no longer achieve their desired narratives. To maintain the desired degree of engagement, the robots must be able to provide a minimum level of flexibility and freedom.

These goals present a design challenge space, where the values of certain goals are frequently in direct opposition to other goals. Being classroom-compatible requires a flexibility that does not distract students from educator goals, while encouraging computational thinking could easily cause that type of distraction. Lowering the barriers to entry could be accomplished through simplifying the software's capabilities, but that simplification could potentially reduce the student's ability to create compelling robot behaviors.

Implementation

To meet these ambitious goals, we decided to create a visual — or graphical — programming language and environment. To encourage future expansion of this environment beyond the Arts & Bots hardware, we named it the CREATE Lab Visual Programmer (CLVP). It is an open-source application written in Java.

Visual programming languages (VPLs) are defined as those that use greater than one dimension for communicating language semantics. VPLs commonly benefit from four features described and defined by Burnett as *concreteness*, *directness*, *explicitness* and *immediate visual feedback*.[2] *Concreteness* represents some aspects of the program as specific objects or values. *Directness* gives the programmer a feeling of direct control or manipulation, and mean the mapping from the problem space to the program space is short and clear. *Explicitness* indicates that some of the semantics of VPLs are explicitly stated in the environment. Finally, *immediate visual feedback* means that changes to the program are automatically made clear to the programmer.

[2] Margaret Burnett. Software engineering for visual programming languages. *Handbook of Software Engineering and Knowledge Engineering*, 2: 77–92, 2001

Based on the goal to lower the barrier CLVP provides a two-step, scaffolded approach for creating robot programs. These two steps were implemented to reflect the process of designing narrative story scenes, and combining these scenes with storyboarding.

The portion of CVLP used to perform the first step is referred to as the Expression Builder (figure 6.1)Ḣere students create static poses or output states for the robot which are called *expressions*, as in emotional expression. Static poses are not static in the sense that no robot component is moving, but rather, expressions consist of a partial definition of the states of each output on the Hummingbird. For example, one expression could be used to describe when the robot is “angry". This expression might set both RGB LEDs to

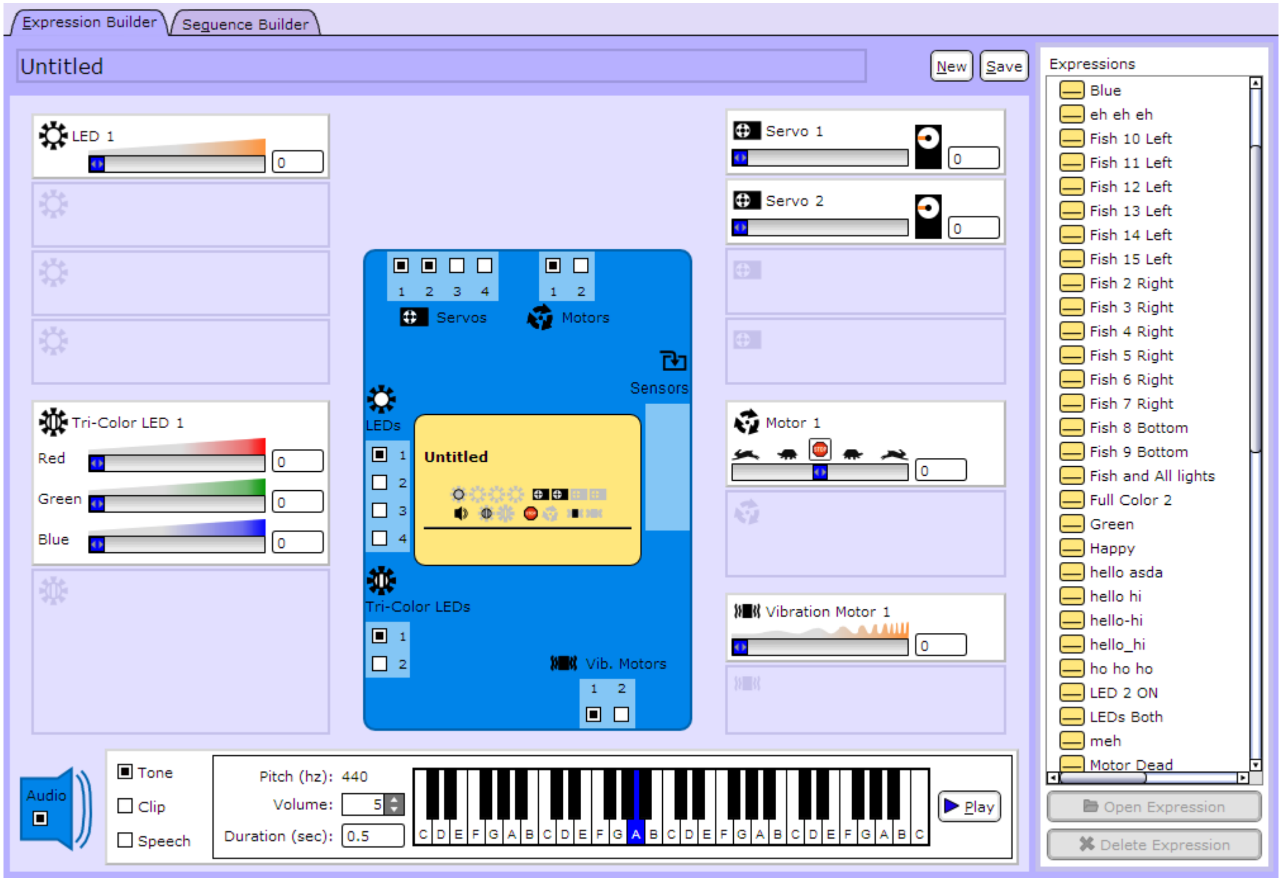

Figure 6.1: A screen shot of the Expression Builder tab showing the illustrated Hummingbird (center) surrounded by output control panels. Existing expressions are shown in a list on the right.

red, while one vibration motor is turned on to full power to create a growling sound. A "happy" expression on the same robot might have the two RGB LEDS set to a calm green-blue color, and the vibration motor turned off.

The second section of the CREATE Lab Visual Programmer is referred to as the Sequence Builder (figure 6.2), and is used to define robot behaviors by joining expressions into a storyboard of robot actions. These storyboards are referred to as *sequences* since they are, at the most basic level, comprised of a time-sequential group of expressions. For example, one could leverage the "angry" and "happy" expressions and create a sequence causing the robot to alternate from "happy" to "angry" and back to "happy" with certain time delays between each transition. The Sequence Builder also provides access to a list of additional structural elements available for creating more complex behaviors. These include an *if-else* conditional based

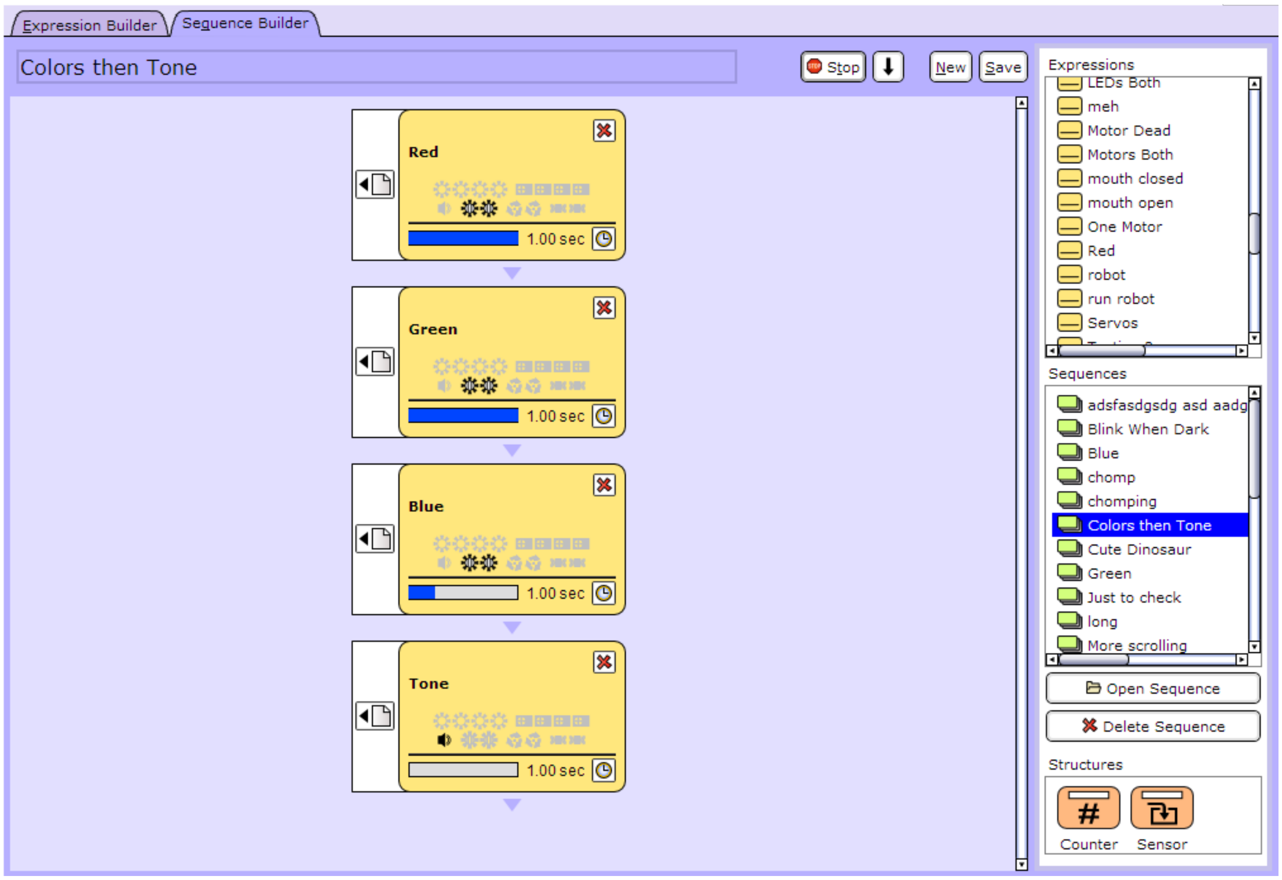

Figure 6.2: A screenshot of the Sequence Builder tab showing the current sequence with four expressions. Existing expressions and sequences are shown in a list on the right.

on sensor readings, called a sensor structure, and a repeating *for-loop*, called a counter structure.

Both the Expression Builder and Sequence Builder are provided inside the same environment window. The two builders are located in different tabs, navigable from the top of the window. Each window has a persistent side-bar palette which contains a file list of all existing expressions. Sequence Builder also has an additional list showing existing sequences, and the list of available structural elements.

Below are presented three key features that the CREATE Lab Visual Programmer implements to meet the stated design goals: *Real World Grounding*, *Live Feedback and Debugging*, and *Incremental Complexity*.

Real World Grounding

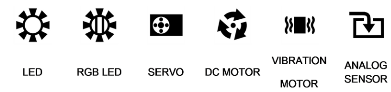

Figure 6.3: The icons used to represent Hummingbird outputs and inputs.

The software environment emphasizes the use of clear physical metaphors to aid recognition for students who are programming an Arts & Bots robot for the first time. After creating a robot, each student will be fairly familiar with the functionality and appearance of the physical hardware of the Hummingbird kits. This existing knowledge is utilized as a foundation for the introduction of the programming task. This idea is closely related to concreteness, in that select components of the interface are designed to imply a direct relationship to physical components and actions. In order to maximize the concreteness of the environment, we omitted variables from the language, since the abstract nature of variables is not required to create compelling narratives, and would require a level of additional complexity that would distract from most class projects and raise the barrier to entry.

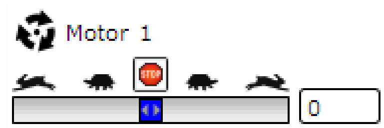

Figure 6.4: An example Motor control panel has a slider bar that has a stop button located above its center location. This button is used to set the motor speed to zero. On either side of the button are silhouettes of tortoises and hares moving away from the center which indicate that the slider is for selecting speed and direction.

Upon opening the software, the Expression Builder Hummingbird image dominates the center of the window and is accompanied by the prompting text stating: "Enable an Output Port." The output ports on the Hummingbird are represented in the software as checkboxes located and labeled in a manner identical to their counterparts on the hardware Hummingbird. Each output type is also associated with an icon that is used on both the hardware Hummingbird and throughout the software (figure 6.3). These icons help students recognize either the appearance or function of each output throughout the software.

The action of checking an output port checkbox is a metaphor for plugging a component into the Hummingbird. Once checked, a control panel, i.e. a region representing and controlling the attributes of that output, is shown in the Expression Builder. The control panels typically contain at least one slider bar that is used to set the state of that specific output ()shown in figure 6.4). Additional visual cues (e.g., tortoise and hare icons representing motor speed) are used to indicate what result to expect from moving the slider.

Live Feedback and Debugging

No syntax errors can be made in the CLVP, making it an easier learning environment. Each control panel in the Expression Builder is designed to have a one-to-one relationship with an output on the Hummingbird. Using the control panels to set an output value, it is not possible to select an out-of-range value, meaning that every expression is valid and executable. Expressions are then combined using the Sequence Builder with a click-and-drag interaction, which snaps them into a valid position in the active sequence. Syntax errors are also not possible when implementing sensor loops in a sequence.

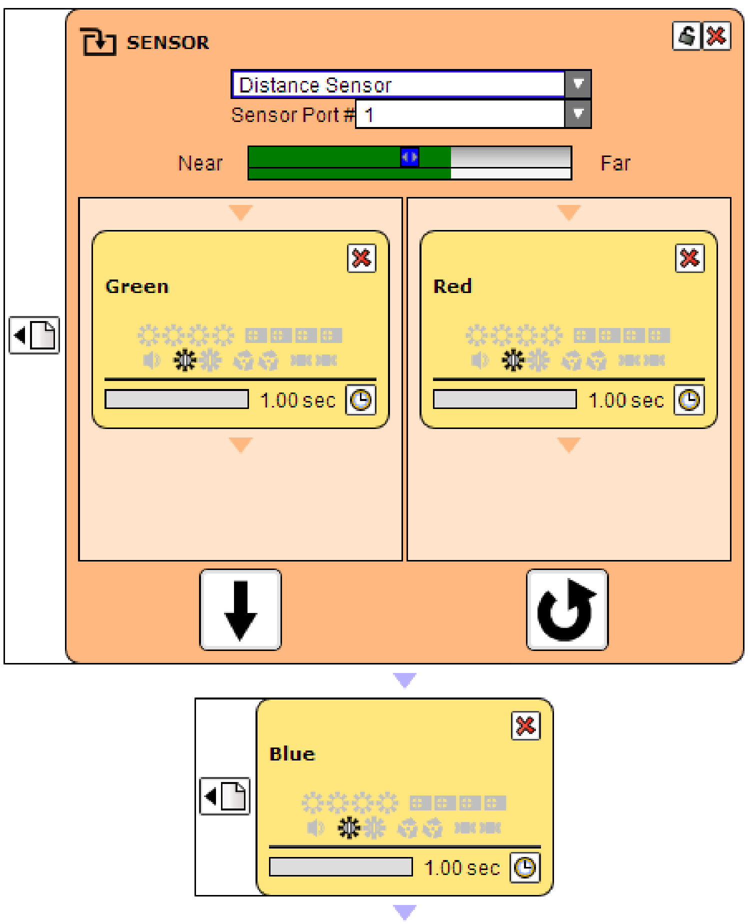

Figure 6.5: A screenshot of a sensor loop. Two drop down menus allow the selection of a sensor type and a port number. The green value bar beneath the menus shows the current live sensor reading as well as the position of the threshold, in blue. If the sensor value is greater than the threshold, the right pane is executed. If the sensor value is less, the left pane is executed. The black arrow at the bottom of each pane allows the programmer to decide whether, following the execution of the pane, the program continues to the next element in the sequence or if it loops back to check the sensor value again. This allows students to create if-else statements, while loops, and infinite loops containing if-else statements.

To aid in the debugging of semantic errors (i.e., errors where the program created does not do what the student expects), the

CREATE Lab Visual Programmer features live visual feedback. While creating expressions, the Hummingbird's physical outputs immediately update to match every change made on a control panel. This allows for a rapid feedback loop where the student adjusts an output value, gauges the effect that the adjustment had on the physical robot and continues to modify the expression values until the physical robot's pose meets her needs. Similarly, the continuous, live readings from the sensors in the Sequence Builder make setting and testing threshold values very straightforward (figure 6.5). Once a threshold is selected, the student can vary the sensed environmental condition, i.e. temperature or light level, to ensure that the sensor reading is above and below the threshold during the times that she expects.

Debugging semantic errors in sequences is also aided by the explicitness of the sequence execution flow. Each program element is directly above and connected by an arrow to the element that follows it during execution. It is straightforward to interpret the sequence of actions that will occur when the program is executed simply by following the arrows. The time delay following an expression that prevents the immediate execution of the following program element is also explicitly written in the bottom portion of each expression block. Along with the specified delay value is a progress bar that, while the sequence is executing, fills as the delay passes. This filling and highlighting action helps students recognize which expression or program element is executing while the program runs, helping with both timing issues and determining where in the program the error occurs. Once the error location is identified, it is possible to edit sequences even while they are running, allowing for immediate corrections. This often leads to experimentation to correct the problem.

Incremental Complexity

To balance the opposing goals of having a low barrier to learning, and having the level of complexity required to create a compelling robot, we designed the CREATE Lab Visual Programmer to be highly scaffolded for novices, while allowing more experienced users to push the limits of the environment to create more elaborate robot behaviors.

The scaffolding is primarily reflected in the two-step programming process, making expressions separate from sequences. This divides the process of finely controlling individual outputs from the high-level design of the robot action. By doing so, the CREATE Lab Visual Programmer enforces the process of creating low-level functions to be used in the primary program, a concept carried through computer science. Segmentation also helps to lower the floor to even the youngest users, who are not ready to plan the creation of a custom sequence from start to finish. One approach is to let these young students tinker with the Expression Builder to customize the robot's pose. Another approach is to have the teacher create a number of simple and clearly labeled expressions that young children can assemble into their own sequences.

Beyond the benefits of the two-step programming approach, many other features of the CREATE Lab Visual Programmer permit the gradual integration of more complicated computer science concepts. At the most basic level, a student can create expressions that individually define the complete output state of the robot and then combine these into a sequence. These basic sequences are fully capable of providing a robot with an interesting narrative behavior, however many improvements can be made by utilizing other features of the environment. When the student becomes comfortable with expressions, the counter structure can be introduced as a way to make repetitive sets of expressions easier to modify and interpret. Meanwhile, the use of sensor structures can provide an added dimension of interactivity with the robot's surroundings. As sequences grow increasingly complex, the idea of creating small pieces of testable, reusable code in the form of subsequences can also become a valuable skill.

Case Study

This case study involves a robot created to express the poem "The Human Seasons" by John Keats, in an eighth grade implementation of Arts & Bots in English Language Arts (ELA) (as described in chapter 5). The robot, which was designed, constructed and programmed by four students, is pictured in figure 6.6. The poem draws association between the stages of a human life and the four seasons of the year.

Figure 6.6: The "Human Season" poem-bot is seen from four sides. Shown clockwise from the top-left: Spring-Childhood, Summer-Adulthood, Fall- Maturity and Winter-Death. In the image of Winter-Death, the Hummingbird and other hardware components are visible inside of the robot's base.

The robot consists of two main structural components: a base that contains all of the Arts & Bots hardware, and, mounted atop a DC motor, a round turntable divided into four sections. Each of the sections is decorated to be representative of both a season and the associated stage of life. As the platform rotates to display each season, the robot activates an RGB LED spotlight to highlight the season facing towards the audience. The robot's sequence also contained expressions with audio clips of the students reading each stanza of the poem that played when the sequence was executed. As each stanza is read, the robot moves to the correct season and illuminates that season with an appropriately colored light.

The sequences and expressions that these students created for their robot demonstrate a good understanding of many of the CREATE Lab Visual Programmer features mentioned previously.

Figure 6.7: The main sequence created for the "Human Seasons" poem-bot is shown center. To either side are views of the contents of the subsequences; to the left is the subsequence for rotating the platform 90 degrees and to the right is the subsequence for the presentation of the Spring-Childhood stanza.

Computational Thinking

In the example shown in figure 6.7, the students designed their primary sequence to be composed entirely of subsequences, shown in green. The third subsequence, titled "90degreerotationspeed-33," is designed to rotate the platform 90 degrees in order to turn to the next season. This subsequence only uses expressions, which provide commands to the DC motor, unlike another style of expression that would control the entire robot. This demonstrates that the subsequence was not designed to be used exclusively during a single transition; instead, it shows that the students have put effort into creating reusable code. In the main sequence, we can see that they do indeed reuse this subsequence before each new season. This saved them the time required to recreate this behavior for each season and permits them to quickly modify all of the rotation subsequences if they would later decide to change the speed of rotation. This is all the more valuable when using a DC motor since the speed and timing aspects are critical to get right when the robot has no feedback and the rotation is based on dead reckoning.

The other subsequence shown in the figure is used to perform the Spring-Childhood stanza. The first expression starts playing the audio performance. Since the delay for this expression is set to .01 seconds, the counter structure beneath begins to execute at approximately the same time as the start of the audio. The counter structure is then used to blink the RGB LED while the audio is played. The use of the counter structure here is a good indication that the students understood the value of using a programmatic loop when performing a repetitive task. One benefit to creating the season performance in its own separate subsequence is that the students were then able to run and debug each part of their program individually. This means that it was possible to make improvements to each season without needing to perform the full poem each time — also indicative of computational thinking.

Low Barrier to Entry

During the Arts & Bots Pioneers, we saw indications that using the CREATE Lab Visual Programmer also caused students to change their perceptions about the difficulty of programming a robot. In response to a short answer survey question, one student reflected on the programming process,saying that "Programming is very challenging but once you get used to it, it's easy." Another student found the process to be easier than expected and explained "I learned that even though programming looks difficult it is actually easier than it seems." These quotes about suggest that the CREATE Lab Visual Programmer was successfully lowering the barrier to robot programming.

Classroom Compatibility and Compelling Behaviors

Students working on the poetry-bot project reported that they thought that the Arts & Bots project aided their appreciation of poetry. One student in the class explained that "Poetry can sometimes be hard to understand but using robotics and giving you a visual can help you understand it. [sic]" From an infrastructure perspective, the teacher was able to smoothly integrate the project in with her curriculum, and install the CREATE Lab Visual Programmer on all of the school-provided laptop computers. The experiences of this class are similar to other classes that have integrated Arts & Bots into their curriculum, such as those examples described in chapter 5. This suggests that the CREATE Lab Visual Programmer successfully achieved the goals of classroom compatibility and enabling compelling behaviors.

Conclusions

The CREATE Lab Visual Programmer was developed to fulfill the goals of the Arts & Bots program, by supporting the creation of complex robot behaviors, and encouraging students to develop technology fluency. In order to do this, the environment needs to have low barriers to entry, be compatible with classroom implementation and support student acquisition of computational thinking skills. The design of the CREATE Lab Visual Programmer has achieved these goals by focusing on the key factors of incorporating real world grounding, live feedback, semantic debugging aides, and the ability to increment the complexity of software as the students gain skills and confidence.

7
Identification of Student Talents

Motivation

Students from underrepresented minorities often do not participate in engineering extracurricular and elective classes that would expose them to engineering and STEM career opportunities. For example, AP Computer Science classes in the United States are typically offered on an elective basis. Test takers of the 2013 AP Computer Science exam were 18.55% female, 8.15% hispanic, and 3.69% black.[1] Similarly, participants in the popular STEM extracurricular FIRST LEGO League in 2013 were 30% female, 11% hispanic and 4% black. In comparison, the distribution of students in US public schools is 49% female, 24% hispanic, and 16% black.[2] Because of on this lack of engagement equity with elective STEM opportunities, students from these underrepresented groups might also not receive encouragement to learn about STEM careers.

Unlike other in-school robotics programs which are usually provided in technology or engineering specific classes, the Arts & Bots program targets teachers of required non-technical courses. However, traditional teacher training in the US provides teachers with little computer science or engineering experience. Non-technical teachers lack the skills and opportunities needed to recognize student talents and affinities towards engineering and computer science. By training these teachers to be aware of computer science and engineering component skills, we hope to also help them recognize

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[1] Barbara Ericson and Mark Guzdial. Measuring demographics and performance in computer science education at a nationwide scale using AP CS data. In *Proceedings of the 45th ACM Technical Symposium on Computer Science Education*, pages 217–222, 2014; and College Board. AP Test 2015 participation statistics. Online, 2015. URL `http://research.collegeboard.org/programs/ap/data/participation/ap-2015`

[2] Grace Kena, Lauren Musu-Gillette, Jennifer Robinson, Xiaolei Wang, Amy Rathbun, Jijun Zhang, Sidney Wilkinson-Flicker, Amy Barmer, and Erin Dunlop Velez Velez. The condition of education 2015. NCES 2015-144. *National Center for Education Statistics*, 2015; and Office of Civil Rights, US Department of Education. Gender equity in education. Online, June 2012. URL `http://www2.ed.gov/about/offices/list/ocr/docs/gender-equity-in-education.pdf`

these skills within their students. This recognition is a first step in guiding students towards future experiences in STEM elective classes, advanced science and math programs, and STEM extracurriculars, which we believe will improve the diversity of future STEM innovators.

We believe that through focused development of the Arts & Bots program, we can: (1) encourage a wide array of student talents and interests, (2) help students manifest these talents and affinities for identification, and (3) support non-technical educators in recognizing these student talents. These goals are centered around the core concept of training non-technical discipline teachers to identify the talents of their students and help those students to grow those abilities. In the end, it is crucial to develop tools and train teachers for identifying and supporting these student talents and interests in order to help each individual learner stretch and maximize their individual strengths.[3] This was highlighted by a junior-senior high school teacher who remarked: "[...] some of the students that excel at Arts & Bots aren't traditionally gifted - who is looking out for and guiding those kids?" Our tools and evaluation of their impact are presented in this chapter.

[3] National Science Board. *Preparing the next generation of stem innovators: Identifying and developing our nation's human capital*. National Science Foundation, Arlington, VA, 2010

Talent Definition Framework

Arts & Bots gives students the opportunity to display and build talent in two specific areas: computational thinking and engineering design.[4] Our definitions of computational thinking and engineering are based on a a range of related models, discussed in this chapter. We looked for common themes across these various models and developed a consolidated, hierarchical list of component skills. We simplified this list to be age-appropriate and suitable for both middle school students and the Arts & Bots project. For example, data visualization is addressed in many computational thinking models, but because of limitations in the Arts & Bots program, is not a skill that frequently surfaces in these interdisciplinary projects. As a last step, we paired each skill with a concrete example of how it could be

[4] The decision to focus on computational thinking and engineering design talents was made after much consideration. While we are also interested in the identification of all student talents, including those in creative writing, visual arts and many others, we believe that non-technical teachers are the less prepared and need additional support in the identification of computational thinking and engineering design talents.

CT Category	Category Components
Problem-Solving	Problem breakdown Redefining problems Strategy decision-making
Abstraction	Modeling Pattern recognition Modularity
Algorithmic Thinking	Algorithm design Incremental development and evaluation

Table 7.1: Computation Thinking Category Breakdown

demonstrated by a middle school student during a project. Our development, definitions, and related skills will be described and explored in the following sections. The completed Talent Definitions document which we provide to Arts & Bots teachers is provided in Appendix A: Talent Definitions.

Computational Thinking

Jeannette Wing, in 2006, wrote an influential article which started the most recent discussions and popular interest in the applicability of the concept of Computational Thinking. She described CT as "[...] a universally applicable attitude and skill set everyone, not just computer scientists, would be eager to learn and use."[5] Wing [2006] defined Computational Thinking as a process that incorporates attitudes and skills allowing real world problems to be solved with methods from computing and computer science. The International Society for Technology in Education and The Computer Science Teachers Associations explain that CT involves restructuring and modeling problems in order to solve them through logical, algorithmic thinking. CT applies students' skills in deciphering complexity, ambiguity, and open-ended problems; persistence and determination in working with difficult problems; and communicating and working with others to achieve a common goal.[6]

Our CT definition includes three categories of skills: problem-solving, abstraction, and algorithmic thinking (see Table 7.1).

Problem solving encompasses three skills which can be used to make solving a problem easier: problem breakdown, redefining problems, and strategic decision-making. Problem breakdown

[5] Jeannette M Wing. Computational thinking. *Communications of the ACM*, 49 (3):33–35, March 2006

[6] International Society for Technology in Education and Computer Science Teachers Association. Computational thinking: leadership toolkit, 2011. URL `http://csta.acm.org/Curriculum/sub/CurrFiles/471.11CTLeadershiptToolkit-SP-vF.pdf`

means taking a large problem and dividing it into smaller problems that are each more manageable. When each sub-problem is solved, the complex problem becomes easier. Redefining the problem is described as recognizing that a given problem cannot be solved with available resources, and as a result, taking the problem and expressing it in a different way so that available tools (such as motors and sensors) are more applicable. Strategic decision-making is the ability to compare and weigh possible strategies and solutions, and make a justifiable decision concerning how to proceed.

Abstraction is the process of taking away unnecessary details in order to expose the essential underlying components of a problem or solution. Our definition of abstraction includes: modeling, pattern recognition, and modularity. Modeling means creating a model or simulation to represent a complex system in order to better understand the system. A skillful model will represent key elements of the system while ignoring superfluous details. Pattern recognition is the ability to consider multiple tasks and recognize the common features that the tasks share. Modularity means recognizing which components may be useful for reuse and creating solutions that are generalizable for multiple tasks.

Algorithmic Thinking is an approach to solving problems that includes both algorithm design, and incremental development and evaluation. Algorithm design is defined as identifying the sequence of simpler steps that must be created and combined in order to create a more complex behavior. Incremental development and evaluation is the process of solving complex challenges by implementing simple, manageable parts. Each part of the solution must be tested and perfected one-by-one before eventually combining them into the full solution.

Engineering Design

Similarly, our Engineering Design (ED) definition is derived from the number of existing models. Engineering Design practices students' skills in real-world problem solving, simultaneously combining new thoughts and concepts, and communicating mental imagery through graphical and media representations. We combined and simplified three separate models of engineering: Systems Engineering, Design Thinking, and Engineering Design Process.[7] We selected these models as the foundations for defining the skills of engineering talent because all three are generalizable to all domains of engineering and together span a complete engineering process from idea conception to prototype evaluation and refinement. Engineering Design is the process of developing a concrete and specific solution for a loosely defined problem within technical feasibility constraints.[8] [9] Our ED definition includes six categories: defining the problem, intentional design, innovating, refining & testing, prototyping, and communicating design (see Table 7.2).

[7] Tim Brown. Design thinking. *Harvard Business Review*, pages 84–95, June 2008

[8] Tim Brown. Design thinking. *Harvard Business Review*, pages 84–95, June 2008; and Nigel Cross. Designerly ways of knowing. *Design studies*, 3(4):221–227, 1982

[9] Nigel Cross. Designerly ways of knowing. *Design studies*, 3(4):221–227, 1982

Defining the problem refers to the way a person identifies the criteria for success, and the constraints and resource limits for a given problem.

Intentional Design relates to the planning stages of engineering through deliberate steps, following an outline. In Arts & Bots deliberate planning is about developing a complete plan for constructing and programming an intended robot, based on relevant criteria and constraints, before beginning work on the robot. Following a plan means persevering despite challenges, rather than changing plans haphazardly while building.

Innovating involves demonstrating creativity in solution generation. This includes generating multiple solutions, solution analysis and evaluation, and "outside-the-box" thinking. Generating multiple solutions requires the ability to brainstorm two or more possible solutions for each challenge rather than pursuing the first solution that comes to mind. Solution evaluation naturally follows solution generation. One must carefully consider the strengths and weaknesses of potential solutions, and describe the reason for making a choice based on success criteria and project and resource constraints. "Outside the box" thinking means coming up with possibly risky, very novel solutions to problems. These solutions might incorpo-

ED Category	Category Components
Defining the problem	Defining the problem
Intentional Design	Deliberate planning Following a plan
Innovating	Generating multiple solutions Solution evaluation "Outside the box"
Refining and Testing	Systematic diagnosis Trade-offs consideration Thorough testing
Prototyping	Design for construction Making it real
Communicating Design	Clear communication of ideas

Table 7.2: Engineering Design Category Breakdown

rate innovative uses of materials, creative mechanisms, or a solution unlike any examples shown in class.

Refining and Testing includes systematic diagnosis, trade-offs consideration, and thorough testing. Systematic diagnosis means utilizing a methodical process of elimination to determine the source of a problem. Trade-offs consideration is defined as recognizing when important goals are at risk of not being accomplished due to resource limitations, then prioritizing the success criteria and reducing or eliminating low priority features in order to reach high priority goals. Finally, thorough testing signifies carefully testing each subcomponent of the robot or program, in addition to the whole system, and comparing test results to the success criteria.

Prototyping requires design for construction, and making it real. When designing for construction, one carefully considers how each component will be constructed and considers the strengths and weaknesses of available materials to avoid problems during construction. Making it real involves taking an idea and creating a physical model that accurately reflects the original idea. The model is carefully crafted, constructed with attention to detail, and successfully and elegantly meets the initial design criteria.

Finally, *Communicating Design* means clear communication of design ideas to teammates, teachers, and others.

Talent Skills Professional Development

We share our Talent Framework with teachers through professional development. The first step in their Arts & Bots training is a discussion of the motivations for focusing on ED and CT talent. We discuss the needs of society for diverse engineers and elaborate on the benefits to students and teachers. During our 2013 to 2015 professional development, we reviewed the definitions and background research of computational thinking and engineering design with the teachers, encouraging open, teacher-to-teacher discussion. We conduct a pair-and-share activity with the teachers and break down Computational Thinking and Engineering Design talents. Teachers receive talent component definitions and examples of how each component manifests in students. The teachers then work in pairs, reviewing the talent definitions for either ED or CT. Each pair then shares their understandings with the larger group. Through the "share" portion of the pair-and-share activity, we clarify talent questions and misconceptions.

After using this PD in 2013 to 2015, we analyzed feedback from teacher interviews and surveys, as described in chapter 4. Teachers asked for more training on talent identification. Some teachers requested shorter versions of the Talent Definitions document to be used as a quick reference tool. For instance, when asked in a interview about the identification definitions provided and what could be added, one teacher said "[...]maybe a more simplified version. [...] Just a few key [statements], which, I know [are] at the top of the page, it had a few key statements or whatever. But yeah, [a simplified version] would have helped." This resulted in the creation of a shorter definition summary for the teachers to reference (as seen in Appendix B: Talent Definitions Summary Handout), and a checklist where the definitions are rephrased as questions (provided in Appendix C: Talent Inventory Handout).

Research on professional development has found that connection and coherence with teacher experiences and knowledge is critically important to the effectiveness of teacher training.[10] We address this

[10] Wendy Martin, Scott Strother, Monica Beglau, Lauren Bates, Timothy Reitzes, and Katherine McMillan Culp. Connecting instructional technology professional development to teacher and student outcomes. *Journal of Research on Technology in Education*, 43 (1):53–74, 2010; and Laura M Desimone. Improving impact studies of teachers' professional development: Toward better conceptualizations and measures. *Educational researcher*, 38(3):181–199, 2009

need through the inclusion of more concrete examples of student built robots. Since most teachers spend much of their time considering student talent and performance in the context of the robots that the students create, we developed a taxonomy of novice built Arts & Bots robot examples, described below.

Exemplar Novice-built Robot Taxonomy

To help teachers more concretely envision how students talents might be displayed by students during Arts & Bots projects, we created a taxonomy of exemplar robots. This taxonomy was generated through affinity diagramming of 179 images of completed novice-built robots from 17 Arts & Bots classes and 21 teacher workshops. Affinity diagramming, sometimes referred to as KJ method after Jiro Kawakita, is an inductive analysis method where qualitative data — often represented by individual sticky notes — is organized to highlight data-supported themes.[11] The resulting taxonomy spans three domains: Mechanical Sophistication, Communication and Artistry, and Computational Sophistication. Because this taxonomy was developed specifically from images of expressive and creativity-focused robot projects, these domains focus on salient features of such robotic creations.

[11] Bruce Hanington and Bella Martin. *Universal methods of design: 100 ways to research complex problems, develop innovative ideas, and design effective solutions*, chapter Affinitiy Diagramming, pages 12–13. Rockport Publishers, 2012

M - Mechanical Sophistication

Mechanical Sophistication is the first domain of the taxonomy and exists along an analog scale which can be described in four tiers. From simplest to most complex they are: 1) direct motion, 2) secondary motion, 3) underactuated motion, and 4) transformation mechanisms. Some examples of these different levels of sophistication are shown in figure 7.1 and figure 7.2.

M1 - Direct Motion

This is the most common type of robot constructed by novices. Moving components of the robot are directly connected to the fundamental hardware/mechanical units. Final motions are directly

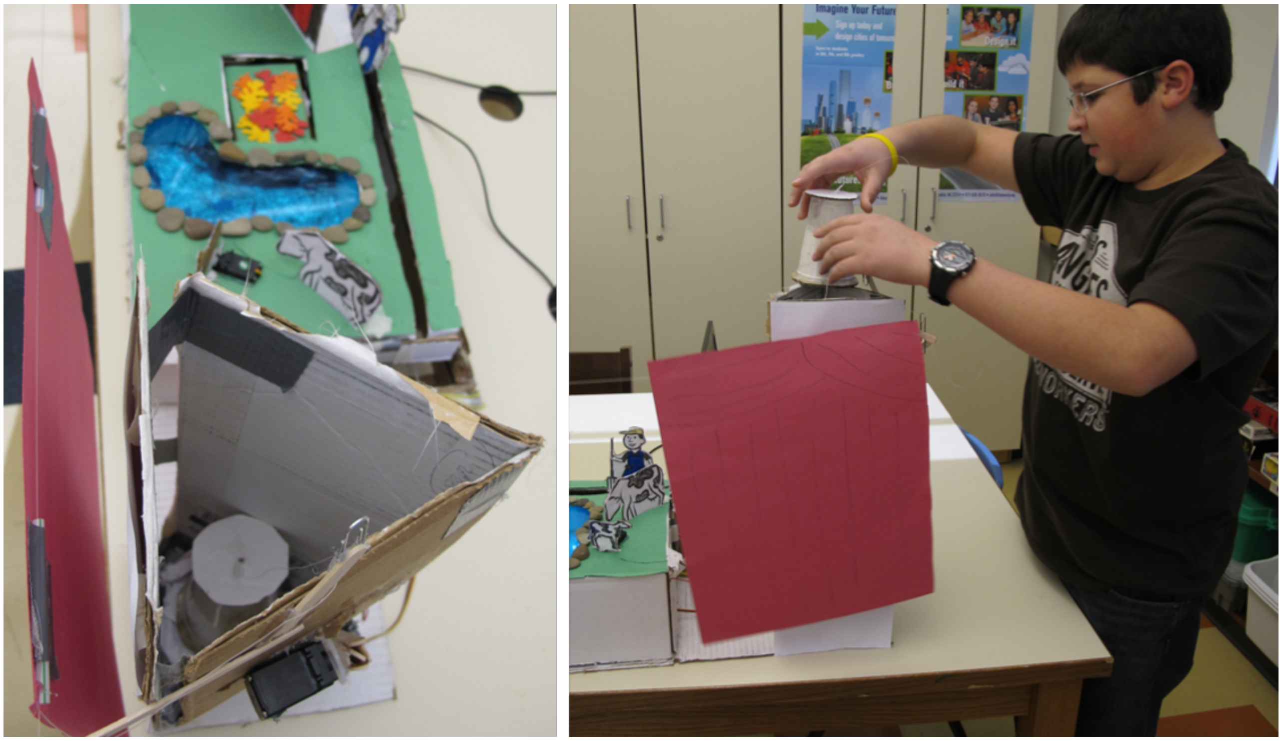

Figure 7.1: A student works on a robot (right) which illustrates the Mechanical Sophistication tier of "Transformation Mechanism." This robot uses counterweights, shown in the student's hand, and a fishing-line pulley system (left) to rapidly open the red paper curtains when the robots' servo opens a trapdoor supporting the counterweights.

derived from the basic actuators of motion (e.g., Motors, Servos, and Vibration motors). For example, moving an arm attached to a servo, spinning a pinwheel with a motor, or shaking a leaf with a vibration motor, are all examples of direct motion.

M2 - Secondary Motion

Here main movement of the robot is still clearly derived from the basic actuators. However, there is some indirectness in the resulting or side-effect motions. These secondary motions are "one step removed" from the basic hardware unit, e.g., changing the length of a stretchy material attached to a lever. Whereas the motion of a motor turning a wheel is a direct motion on the robot, but if that wheel causes the robot to move across the ground, this is a secondary motion. Unlike an underactuated motion, however, the robot is still always fully in control of these secondary motions.

Figure 7.2: Four robots illustrating different degrees of Mechanical Sophistication, and Communication and Artistry: (clockwise from top left) audience consideration with direct motion; audience consideration with transformation mechanism; practical construction with transformation mechanism; practical construction with direct motion.

M3 - Underactuated Motions

A robot is underactuated when a single basic actuator causes motions in more than one degree of freedom. The resulting degrees of freedom cannot be controlled independently. For example, a motorized robot lever with a freely moving bell on the end. While the robot has direct control of the lever, the ringing of the bell is an uncontrolled (e.g, underactuated) resulting motion. Another robot could have a model spider dangling on a string, which is lowered vertically with a pulley driven motor, but has uncontrolled side-to-side motion. Sometimes these motions may include the purposeful use of randomizing physics, such as dropping marbles to simulate rain.

M4 - Transformation Mechanisms

In these examples, the main motions of the robot are distanced from the basic actuator motions, and are enhanced and transformed by mechanisms. Some transformations allow the robot to exhibit motion or forces otherwise not possible with the primitive motion components, such as a smooth oscillating motion or a high speed linear motion. The robots when examined make use of principles of mechanical advantage and mechanisms, including levers, cams, sliders, etc. The motions can also be the result of a chain of mechanisms or mechanical transformations. An example of this type of robot is shown and described in figure 7.1. These motions have more than one step of removal, as seen in the secondary motion, but still have the one-to-one relationships between actuators and resulting motions, differentiating them from underactuated motions.

A - Communication and Artistry

Communication and Artistry has two levels. The most basic is "Practical Construction," and the more advanced is "Consideration of the Audience." The visual form and communicative elements of the robot both contribute to classification of a robot into these categories. Some examples of each level are shown infigure 7.2.

A1 - Practical Construction

- *A1a Non-Distracting Details* - When the raw materials from which the robot is constructed are obvious and unhidden, it can distract from the expressed idea or purpose of the robot. The wires and hardware components themselves are obvious, visible, and not contributing to the message of the robot. When the materials chosen are solely practical or mechanical in nature and no materials are used to cover or decorate the raw structure or mechanism, the outcome is indicative of a lower tier Communication and Artistry. Conversely, excessive details that are not relevant to, or worse, that are distracting from the idea being expressed are also not considered to be contributing to the artistry.

- *A1b Direct Communication* - The robot is a direct and literal representation of the idea being expressed. For example, a robot dog is constructed to represent a dog. Building a direct model without much novelty added to the interpretation does not signify a high artistry level.

A2 - Consideration of the Audience

- *A2a Surprising Form and Relevant Detail* - When robots are constructed with audience consideration in mind, it signifies a higher level of Communication and Artistry, revealing surprising forms with relevant details. The robot can be constructed from standard materials, but the form and appearance of the robot are surprising or non-obvious. The media and materials used enhance the idea expressed by the robot rather than detracting or distracting from it. The perspective of the viewer is taken into account to better express ideas, e.g. components are hidden from view to minimize distractions.

- *A2b Metaphorical* - Some robots incorporate novel ideas and artistic visions, taking the robots beyond a direct model of the idea being expressed. Using metaphors to represent deeper or more abstract ideas, the robot expresses a new interpretation of the idea and represents a high tier of Communication and Artistry.

C - Computational Sophistication

Computational Sophistication describes the level of sophistication of the robot program. The categories and their descriptions are tailored to the programming language used in Arts & Bots (CLVP described in chapter 6), and the resulting program structures and behaviors exhibited in typical Arts & Bots robots. There are two axes that comprise our Computational Sophistication taxonomy: *Structure* which describes how carefully individual behavior sequences are designed and implemented, and *Interactivity* which describes how sensors are used to create interactive behaviors.

Cs - Structure

- *Cs1 Repetitive Action* - A robot exhibiting repetitive action is simple and consists of one or more states, or *expressions*, that are output by the robot cyclically. This includes, for example, a simple dog robot with two expression states: "tail left" and "tail right," which alternate in a loop. Repetitive actions can also encompass a larger number of expression states, as in a robot with arms and lights that cycles through a number of different poses and light combinations in a dance.

- *Cs2 Storyboard* - Storyboard robot behavior differs from repetitive action behavior by the existence of a fixed, intentional start and end state. The robot moves through a series of actions while communicating a coherent concept or narrative. For example, a robot traffic light with an animated car can be programmed to sequentially light red, yellow, and green LEDs before the car moves forward a set distance. Similarly, an art-producing robot with an attached marker could draw a specific image, such as a star polygon, through several intentional motions, and then stop when it has completed the drawing.

- *Cs3 Synchrony* - Synchrony robot behavior is similar to a storyboard in appearance, as behavior is also intentionally laid out in a specific series of actions, with a fixed start and end points. However, Synchrony is set apart from the storyboard by the relative importance of the timing of the robot actions. In synchronous programs, the timing of the robot actions are carefully and purposefully delineated by external factors. For example, a theater robot with moving actors requires motions and actions to be carefully timed to happen alongside with the audio of the robot. Additionally, if two or more robots were programmed to interact, the timing of both robots would need to be carefully synchronized following timing agreed upon in a script.

Ci - Interactivity

Beyond the structuring of robot programming and behaviors, the computational complexity of novice-built robots is also dependent on how sensors and inputs are utilized to add interactivity and feedback to robot behaviors. Some robots created by novices have no interactivity or sensors. However, by the definition of a robot (a device that can complete tasks and respond to its environment autonomously), these sensor-less novice built devices are more electromechanical devices or computational sculpture than true robots.

- *Ci1 Triggers and Forks* - At the simplest level, robots use sensors in straight-forward "if-else" structures, which determine behaviors based on whether certain threshold conditions are reached by sensor values. Abstractly, these "behavioral forks" determine whether a robot will perform behavior 'A' or behavior 'B' based on the sensor or input values. For example, a simple robot could be programmed to wave a flag left if an infrared distance sensor detects an object less than one foot away, or wave the flag right if it does not. An even simpler version of this fork interaction uses the sensor reading as a trigger condition, meaning the robot only does an action if the threshold is met. Otherwise, it performs no action. For example, a simple robot is programmed to wait before acting and then move forward when triggered by bright light detected by a light sensor.
- *Ci2 Hierarchical Logic* - Yet tier of sophistication is achieved when multiple "if-then" statements are used in the robot program to form more elaborate logic trees or hierarchies. For example, a

robot programmed could be programmed to work as a range detector which uses an IR distance sensor and lights up red when an object is closer than 6 inches, yellow when the distance is measured to be 6 to 12 inches and red if the object is greater than 12 inches away. These robots can also combine if-else statements in hierarchies to create robots that modify behaviors based on two or more sensor values. For example, a robot programmed to open or close a greenhouse roof based on a number of cases of specific light and temperature sensor values.

- *Ci3 Feedback-Based* - The highest tier of computational sophistication that can be achieved with the Arts & Bots programming environment are behaviors that are built around concepts of engineering feedback. Whereas the previous tiers of interactivity combine the use of outputs and sensor inputs, feedback interactions have direct cause-and-effect relationships between inputs and outputs. When our novice-built robots exhibit feedback, it is most commonly in the form of a bang-bang-style control scheme. For example, a robot could be programmed to maintain a certain distance from an object in front of it. If the distance is too large, it is programmed to move closer. If the distance is just right or too close, the robot moves away. In this way, the robot is constantly in motion, adjusting its position with feedback from the sensor. Another example would be a robot with a temperature sensor that controls operation of a fan.

Training Teachers on Novice-Built Robot Taxonomy

In response to teacher requests for more training on talent identification, we enhanced PD with photos of example student robots. To allow comparison, examples were from the same class. We presented student projects to teachers, discussing positive and negative qualities of each. Robots were discussed in terms of the three components of the taxonomy. We related ED to Mechanical Sophistication and Communication and Artistry. We related CT to Computational Sophistication. Admittedly, many of the ED and CT talent components are expressed through the process of creating a robot, and are not necessarily evident solely by viewing the final product. However, discussion of students' robots provided a basic framework for delving into concrete talent examples.

Research Focus and Preliminary Evaluation

We worked with two school districts to evaluate of our talent identification tools. We collected data on the tools' and trainings' effectiveness via quantitative Talent Inventories and qualitative teacher interviews. All of our quantitative analysis was performed using SPSS.

Our evaluation examines whether providing a teacher with our talent-identification professional development, and the opportunity to implement a creative technology program, like Arts & Bots, changes their recognition of computational thinking and engineering design student talents. It is important to note, that in this intervention, we are not treating ED or CT Talent as outcomes that we seek to improve. The goal of the project is to find exceptional students whose talent was not previously recognized by the teachers. We are not looking for the talent score of all students to increase.

Talent Inventory

The Talent Inventory is completed by each participating teacher on three separate occasions. The first Talent Inventory is completed at least two weeks (preferably more) before the start of their implementation, the second is completed at the start of their implementation, and the third is completed after the completion of the implementation. Talent Inventories were collected from eleven teachers across eleven classes between December 2014 and May 2015 (1.5 years). Each student is rated by the teacher from 1 to 7 in both Engineering Design and Computational Thinking. Numerical scores are supplemented with descriptions "1 - Does not show special promise in this area," "3 - Shows occasional evidence of talent," "5 - Shows frequent evidence of moderate talent," and "7 - Shows frequent evidence of outstanding talent." Training the teachers on our talent framework allows us to treat these scores as a multi-item scale. If we were to include the talent framework as the scale, it would take an infeasible amount of time for teachers to score every talent sub-category (e.g., problem-solving, abstraction, algorithmic thinking, etc. as seen in table 7.1 and table 7.2) for every student. We assert that by training the teachers to apply our talent framework we prepare them to provide ratings that encompass those underlying features while greatly decreasing the assessment burden.

Because of the self-administered nature of our teacher evaluation, all three Talent Inventories were not reliably completed for each class. To have a suitable sample size, we compared pre-scores from either the first or second inventory with post-scores from the third. The second inventory score was preferred if both the first and second were completed. Matched sets of pre- and post-scores were available for 347 students.

During two co-taught classes, two teachers performed pre- and post-scoring of the same set of 41 seventh grade students. Comparing the pre-CT, pre-ED, post-CT, and post-ED scores from each teacher pairwise by individual student, we found that all four of the score sets demonstrated significant levels of correlation (pre-CT $r=.467$, $p=.002$; post-CT $r=.657$, $p<.000$; pre-ED $r=.493$, $p=.001$; post-ED $r=.663$, $p<.000$). However, while correlated, a paired samples t-test, indicated that the scores were also significantly different. For the pre-CT scores, between teacher 1 scores ($M1=3.15$, $SD=1.152$) and teacher 2 scores ($M2=4.41$, $SD= 1.40$) was a significant difference ($t(40)=-6.861$, $p<.000$). Similarly pre-ED, post-CT, and post-ED scores were also significantly different (pre-ED: $M1=3.31$, $M2=4.10$, $t(40)=-4.261$, $p<.000$; post-CT: $M1=3.46$, $M2=4.29$, $t(40)=-4.204$, $p<.000$; post-ED: $M1=3.46$, $M2=4.49$, $t(40)=-4.924$, $p<.000$). This indicates that while the teachers had generally correlated scores, with high scoring students receiving corresponding high scores from both teachers, teachers did not score on a consistent scoring scale. Teacher 1's mean scores were consistently lower than those of teacher 2. Spacing between numerical scores is subjective and variable by teacher, and also dependent on teacher experiences — i.e. the range of talents observed by a teacher will set her expectations for the endpoints of the scale. This means that direct comparisons between numerical scores are not currently possible without further refinement of training and tools. Nevertheless, teacher-perceived rankings of student talents and identification of high- and low-talent students compared to class averages is useful once the numerical scores are normalized.

To permit the meaningful combination of Talent Inventory data from different classes and teachers, we convert numerical talent scores to class ranking scores. We calculated each students' rank in the class as a percentage of class size. For example, a student who has a score above 5 of her peers in a class of 20 would be in the 25th percentile. This percentile rank scale is consistent with modern giftedness research, where a student scoring in the top 90th percentile among her peers in a domain is identified as being exceptional.[12] Each student has four percentile ranks, two for ED and two for CT on both the pre-inventory and the post-inventory, respectively.

[12] National Association for Gifted Children. Redefining giftedness for a new century: Shifting the paradigm, 2011. URL https://www.nagc.org/sites/default/files/Position%20Statement/Redefining%20Giftedness%20for%20a%20New%20Century.pdf

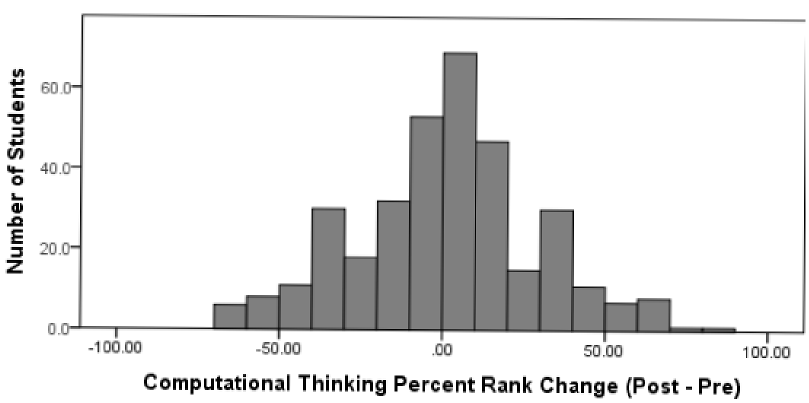

Figure 7.3: Computational Thinking percent rank change, N=347, M = 1.1, SD = 28.4.

Standard parametric tests are not appropriate for our research focus and data. Parametric tests evaluate hypotheses about differences in the mean scores of a sample. Conversely, our research focus is on a small number of exceptional students and not the sample mean as a whole. ANOVA and t-tests also rely on the assumptions of normally-distributed, interval data which are not met by Talent Inventory scores.

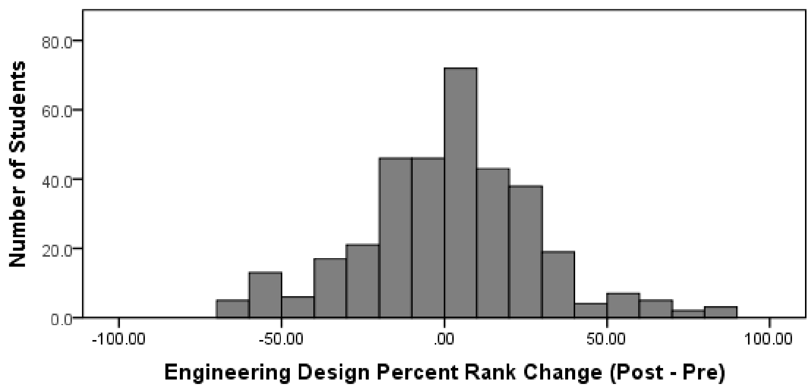

Figure 7.4: Engineering Design percent rank change, N=347, M = 1.4, SD = 26.8.

In order to assess teachers' change in perception of students, we compared change in student percentile ranks from pre to post (figure 7.3 and figure 7.4). These distributions are roughly centered around a percentile rank change of zero as is appropriate and expected as the mean percentile for each class is always approximately the 50th percentile (CT percentile rank change M=1.1, ED percentile rank change M=1.4).

The distributions of CT and ED percentile rank changes had relatively large standard deviations (SD=28.4 and SD=26.8 respectively). The large standard deviations indicates that the percentile rank changes of some students vary greatly from the means of the distributions. However, the positive excess kurtosis of the distributions (CT kurtosis = .192, ED kurtosis = .777) indicate that the distributions are leptokurtic, indicating that a greater number student rank changes are concentrated around the mean than would be in a normal curve. Most students' ranks changed very little while some changed a lot. For CT, 17 students (4.9%) increased 50 percentiles or more, and 14 students' ranks (4.0%) decreased by 50 percentiles or more. For ED, 17 students' ranks (4.9%) increased by 50 percentiles or more, and 18 students' ranks (5.2%) decreased by 50 percentiles or more. These outliers on the distributions show that teacher perceptions of some students' talents are changing greatly. For 4.9% of students, their CT or ED talents are newly recognized as being much higher than expected. Teachers' positive assumptions about students' talents are being challenged and found to be lower than expected for 4.0% and 5.3% of students for CT and ED respectively. Conversations with teachers during subsequent professional development sessions suggest that some teachers originally expect academically talented students to automatically be skilled in CT and ED, but may change their minds after observing students during class.

Teacher Interviews

Qualitative analysis of teacher interview data is ongoing, and we are developing a coding scheme that will allow us to quantitatively analyze their open-ended responses. However, preliminary interview data does suggest that teachers are identifying talent through their Arts & Bots implementations. We present here some anecdotal quotes from the interviews and some qualitative discussion of potential outcomes to aid in contextualizing the presented Talent Inventory data.

Interviews included questions about recognizing talent. Sometimes teachers expressed uncertainty in their ability to recognize talent, saying, "I don't know if I'm missing it, if I'm too hard on myself, because I keep reading over what they all mean, you know? And I'm like, am I seeing it? Am I not seeing it? I don't know," (computing teacher). However, teachers often stated that they were able to recognize previously hidden talents in their students: "...when this new lesson comes into play..., sometimes you see different sides to people. You see a different ability that was hidden," (science teacher).

In interviews, teachers commented on specific components of our talent framework. Innovating was mentioned by several teachers, for example: "[They] take different materials, manipulate them ... I would never have thought to manipulate a material in that way. I started to see some talent from people that started doing that. They look at a bottle ... Like 'oh, I can use this in a whole bunch of different ways' ... I started to really see some design talent come out of kids like that, or engineering talent," (health teacher). One teacher not only recognized designing for construction, but also communicating design and abstraction, "... there are some who really have a high aptitude for figuring out, well, I need to make sure it holds up, so I need to add this to it, and they kind of take the others with them, which has been interesting to watch, and it's been a lot of fun. ... Now I do have some who are good at thinking more abstractly ... they're really good about bringing everyone else with them. Like they help each other, and a lot of times they don't even ask for me. They just start talking to each other and they figure it out, which is really cool," (art teacher).

Conclusions

In this chapter, we presented a talent definitions framework with three primary categories of skills in CT talent and six categories of skills for ED talent. This framework was created to help non-technical teachers better understand and recognize student skills that contribute to talents in CT and ED. To further aid teachers, we presented a taxonomy for classifying novice-built robots which distinguishes three primary domains of differentiation: Mechanical Sophistication, Artistry and Communication, and Computational Sophistication. Finally, we presented early findings from data collected with teacher surveys and interviews. Using teacher completed Talent Inventories, we examined how perceived rankings of student talent changed over the course of an Arts & Bots project. For 4.9% of students, their CT or ED talents were newly recognized by teachers as being much higher than expected.

8

Development of Student Evaluation Tools for Creative Robotics

The Arts & Bots program and many other creative technology extracurricular and in-school interventions are being developed or are in use today, all with goals related to the support of middle school students' technological fluency. Technological fluency, when compared with technological literacy, is the capacity to be a creator of new tools and solutions, and not merely a competent user of available tools. Technological fluency — which includes skills and knowledge of tools and materials, as well as attitudes towards technology — is crucial for students in both engineering and computer science.[1] It is critical that instruments assessing student technological fluency are available for the development and evaluation of these educational robotics interventions, and for the comparison of student experiences and outcomes.

Portions of this section first appeared in:

Cross, J., Hamner, E., Zito, L., Nourbakhshh, I., & Bernstein, D. (2016). Development of an assessment for measuring middle school student attitudes towards robotics activities. In 2016 IEEE Frontiers in Education Conference (FIE).

[1] Marina U. Bers. Engineers and storytellers: Using robotic manipulatives to develop technological fluency in early childhood. In Olivia N Saracho and Bernard Spodek, editors, *Contemporary Perspectives on Science and Technology in Early Childhood Education*, pages 105–225. IAP, 2008; and Debra Lynn Bernstein. *Developing Technological Fluency through Creative Robotics*. PhD thesis, University of Pittsburgh, 2010

The instruments that we developed to help address these needs cover three subjects (listed in order of decreasing specificity): student experiences during Arts & Bots; student technical knowledge; and student attitudes towards technology. The complete pre- and post-surveys developed and finalized in 2015 are shown in Appendix D: Student Pre-Surveys, and Appendix E: Student Post-Surveys. Items addressing student experiences during Arts & Bots are primarily in the format of short-answer questions that provide qualitative data to support Arts & Bots improvement through formative evaluation.

Items assessing student technical knowledge are more generalized. They allow for evaluation of the program's efficacy in increasing student technical knowledge. These items cover two areas of interest: student understanding of hardware components, and student understanding of the systems engineering concepts of input, output, and processing. Finally, assessment items for student attitudes towards technology are the most generalized, and address two areas: students attitudes towards robotics activities, and student perceptions of STEM careers.[2]

[2] Notably missing from this list, is a measurement of student knowledge of and skills in the disciplinary content that the Arts & Bots project is being implemented in. This is an intentional omission due to difficulty of developing valid assessments for each of the many disciplines and topics chosen by teachers in this study and for analyzing those results collectively. However, in the future, it would be interesting to investigate the effects of integration on student disciplinary content outcomes through evaluation co-developed with the disciplinary teacher.

Student Experiences During Arts & Bots

The items developed for student experience evaluation are primarily short answer questions that we use to collect qualitative data about the Arts & Bots program. These short answer questions are:

- Should other students have this experience? Why or why not?
- How did this experience change how you think about technology?
- Did you enjoy doing this project? Why or why not?
- What was the best thing that you learned during the project?
- Do you have any suggestions for improvements?

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). To quantitatively analyze the qualitative student responses, we developed a coding scheme. Two educational robotics researchers on the Arts & Bots research team coded the responses. When coding open-ended student responses, the 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 8.1. Many cross-cutting themes in responses were identified during the Arts & Bots Pioneers study. For example, the code for "Fun and Enjoyment" was applicable both to responses to "Did you enjoy this project?" and to "Should other students have this experience? Why or why not?"

The raters developed and assigned codes from a set of 58 codes based on these themes. In addition to this universal code set, question-specific codes were also defined in the coding scheme. In total, a rater chose 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?" Each separate idea presented in a response was assigned a code. However, duplicate codes were never assigned to a response. 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 answers and agreed upon the final codes to be assigned to each response. The complete coding scheme is presented in Appendix G: Short Answer Coding Instructions.

Table 8.1: Interrater reliability on short answer question coding

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 experience? Why or why not?"	0.642	<0.001
Overall	0.762	<0.001

We also created a set of Likert-type questions — comparing a student's Arts & Bots project experience to their expectations — to supplement the short answer items. These questions were generated following the coding of the short answer questions during the Pioneers phase of the Arts & Bots project. We found that student responses across the short answer questions frequently reflected how the different aspects of the project were more or less challenging than students expected. More information about these initial results are reported in Cross et al. [2015][3] and chapter 9. To develop a more complete understanding of how student assumptions and expectations are changed by Arts & Bots projects, we introduced four additional items covering four primary Arts & Bots activities (below). These allowed us to investigate our finding with both specificity and breadth.

[3] Jennifer Cross, Emily Hamner, Christopher Bartley, and Illah Nourbakhsh. Arts & Bots: Application and outcomes of a secondary school robotics program. In *Proceedings of the 2015 IEEE Frontiers in Education (FIE) Conference*, 2015

How did your Arts & Bots experience compare with your expectations?

- Coming up with an idea and designing a robot is...
- Building a robot is...
- Programming a robot is...
- Working on a team is...

Responses: (1) much easier than I thought, (2) easier than I thought, (3) about as I expected, (4) harder than I thought, and (5) much harder than I thought.

Technical Knowledge Scale Development

The research instrument we created for evaluating technology knowledge was designed to answer questions regarding whether Arts & Bots was effective in helping students to develop foundational technical knowledge, as part of Technological Fluency. The initial technical knowledge items were developed for the evaluation of the Robot Diaries out-of-school program, were primarily based on work by Bernstein [2010],[4] and were implemented without any adaptation during the first Arts & Bots Pioneers in-school pilots. These technical knowledge items, described in detail in table 8.2 consisted of: multiple-choice items on basic circuitry concepts, multiple-choice

[4] Debra Lynn Bernstein. *Developing Technological Fluency through Creative Robotics*. PhD thesis, University of Pittsburgh, 2010

items on systems engineering concepts, and a set of short answer questions covering technology, sensors, robots and system analysis.

Table 8.2: Original Robot Diaries Technical Knowledge Items

Construct	Item	Source
Defining technology	How do you define 'technology'?	Original question
Understanding systems	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. [list of 10 examples]	Sullivan [2008]
Understanding systems	Emily made a flower. The flower's petals can open and close. The petals are usually open. But if someone touches the flower, the petals close. What parts did Emily use to make the flower? Why do the petals close when someone touches it? [also shows a video a flower robot in action]	adapted from Bernstein [2010]
Circuits	Choose whether each bulb will be on or off in the following circuits.	Silk and Schunn [2008]
Circuits	For each component listed below, answer whether the DIRECTION of the component matters when you place the component in a circuit. [battery/LED/wire]	Silk and Schunn [2008]
Sensors	What is a sensor?	adapted from Bernstein [2010]
Sensors	Where can you find a sensor?	adapted from Bernstein [2010]
Sensors	Describe one sensor you've seen before and explain how it works.	adapted from Bernstein [2010]
Robots	What is a robot?	Original question

Systems Engineering

The technical knowledge portion of the student survey contains a set of questions designed to measure a student's understanding of the systems engineering concepts of inputs, outputs and processing of information. These concepts are widely applicable to systems ranging from robotics to biological systems to ecosystems. The systems engineering questions are adapted from Sullivan [2008][5] 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" action of the system:

[5] Florence R Sullivan. Robotics and science literacy: Thinking skills, science process skills and systems understanding. *Journal of Research in Science Teaching*, 45(3):373–394, 2008

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.

Answer options: Input, Output, Processing (provided to students as multiple choice for each question)

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

Source: Florence R Sullivan. Robotics and science literacy: Thinking skills, science process skills and systems understanding. *Journal of Research in Science Teaching*, 45(3):373–394, 2008

These items remained unchanged from the Arts & Bots Pioneers study to the Arts & Bots MSP study.

Hardware Components

The technical knowledge section originally contained short answer and multiple-choice items that addressed technology knowledge concepts in circuitry and types of hardware components. An example of a circuit questions is shown in figure 8.1.

The data collected from initial classroom pilots showed no significant improvement in students scores on knowledge items associated with circuit components. Upon further consideration, and interviews with the Arts & Bots Pioneer teachers, we realized that, while the extracurricular programs included instruction on basic circuit concepts, the in-school Arts & Bots programs did not. During

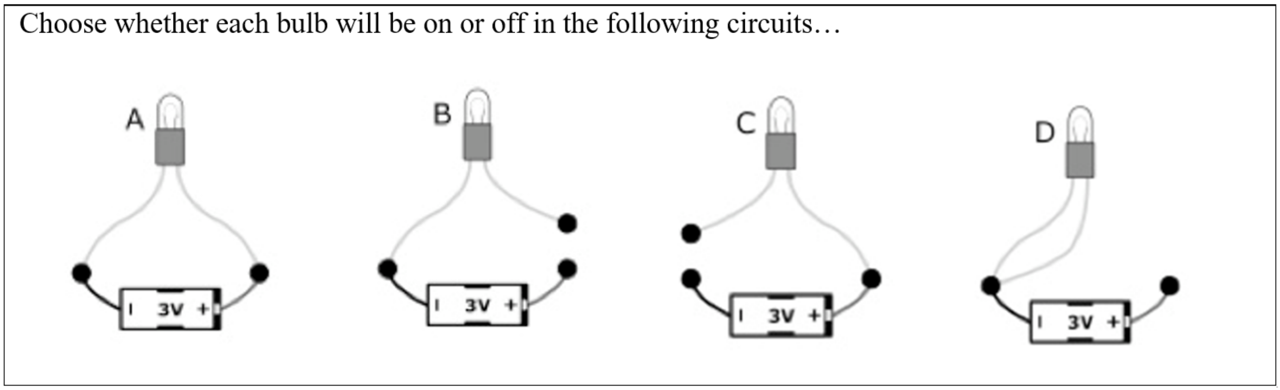

Figure 8.1: Example question from the earlier Robot Diaries, which evaluated understanding of circuit concepts.

the partner teachers' residency, we had eliminated instruction on circuitry to maximize the amount of class time spent on the disciplinary topic. Therefore, we focused only on the essential concepts for construction of Arts & Bots robots. The program goals of the Arts & Bots in-school program prioritized high level technical concepts and not basic circuitry. And so, we decided to develop a revised knowledge assessment tool aligned with program goals, instead of adjusting the curriculum to match the out-of-school evaluation tools.

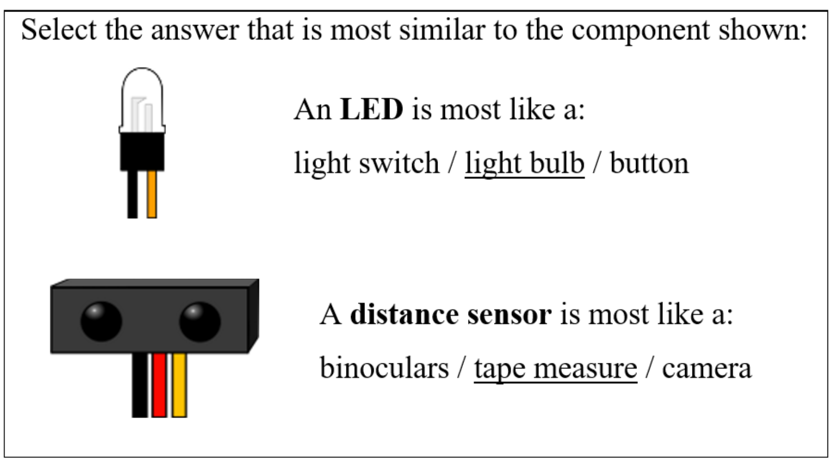

Figure 8.2: Two example items from the revised hardware component knowledge section with component analogies (correct response underlined).

We modified the knowledge survey to match the instruction that was being provided in the Arts & Bots program. To do so, we first removed the irrelevant circuit concept multiple-choice questions. We then replaced that section of the survey with a new question set focused on recognition and understanding of nine Hummingbird Kit hardware components. We asked students to match hardware components with analogies for how the components function. These items were accompanied by images of the Arts & Bots component, as we heard during teacher interviews that the terminology used across projects was not consistent. Two examples of this question format are shown in figure 8.2. The complete list of items follows:

Select the answer that is most similar to the component shown.

1. An LED is most like a: *light switch/ light bulb/button*
2. A temperature sensor is most like a: *thermometer/ heater /speaker*
3. A servo is most like a: *elbow/hands on a clock/knob*
4. A vibration motor is most like a: *speaker/seismograph/unbalanced washing machine*
5. A distance sensor is most like a: *binoculars/tape measure/ camera*
6. A microcontroller board is most like a: *computer/memory card/power outlet*
7. A motor is most like a: *pulley/steering wheel/ engine*
8. A light sensor is most like a: *camera/light switch/ magnifying glass*
9. A potentiometer is most like a: *record player/volume knob/button*

Reviewing of these items during the Pioneers study, we determined that the scale had a low level of internal consistency and the student total scores were reflective of poor scale design. While as experts, we anticipated that a student would interpret the prompt of "most similar" to be a *functional* similar, data suggested that many students were instead interpreting that to mean *visually* similar. Further, student data may have also been confounded by the analogy structure, which required students to understand both the hardware component in question, and the object of comparison.

To resolve this, we created a new hardware-component-understanding scale, modeled on a matching activity, where components where paired with their descriptions, as shown below:

Match each component to its description.
Not all descriptions will be used.

Components:

1. distance sensor
2. LED
3. light sensor
4. microcontroller board
5. motor
6. potentiometer
7. servo
8. temperature sensor
9. vibration motor

Descriptions:

A. A set of instructions that tell a computer what to do.
B. Can be set to a precise angular position.
C. Changes electrical signals into sound.
D. Creates light.
E. Detects heat.
F. Detects levels of brightness and darkness.
G. Detects moving objects.
H. Detects pressure or force.
I. Detects the amount of space between itself and an object in front of it.
J. Is a small programmable computer.
K. Produces a rapid back and forth motion.
L. Produces rotating motion.
M. Senses angular position.
N. Starts or stops the flow of electricity through a circuit when it is pressed or moved.

This set of items similarly proved to not meet our needs during the pilot evaluations. Students would incorrectly select a definition for one component, then eliminate that definition from the list, despite it being a correct fit for a different item. This interconnection resulted in the difficulty of individual items varying depending on their order of completion. The final solution, which was implemented for the Art & Bots Math-Science Partnership student surveys, was a set of multiple choice items with four options each, as shown in table 8.3. We then combined this with a custom set of Input-Output-Processing-type items, inspired by Sullivan [2008][6], but focusing on the role of one of the nine hardware component types. These new hybrid systems engineering and components items are listed below:

[6] Florence R Sullivan. Robotics and science literacy: Thinking skills, science process skills and systems understanding. *Journal of Research in Science Teaching*, 45(3):373–394, 2008

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.

Answer options: Input, Output, Processing (provided to students as multiple choice for each question)

1. The glowing of an LED on a traffic light
2. The detection of your hand by a distance sensor in hand dryer
3. The cooling of a temperature sensor in a refrigerator
4. A microcontroller board in a mp3 player determining what song to play next on a play list
5. The spinning of a motor in a robot
6. Covering a light sensor in a night light
7. Twisting a potentiometer in a light dimmer knob
8. The repositioning of a servo on a remote control airplane
9. The shaking of a vibration motor in a cell phone

Choose the best description for each component.
1. Distance sensor: Detects when there is or is not motion. Senses angular position. Produces a small rapid back and forth motion. Detects the amount of space between itself and an object in front of it.
2. LED: Creates light. Detects heat. Changes electrical signals into sound. Detects levels of brightness and darkness.
3. Light sensor: Heats or cools objects. Creates light. Detects levels of brightness and darkness. Starts or stops the flow of electricity through a circuit when it is pressed or moved.
4. Microcontroller board (such as the Hummingbird board): Starts or stops the flow of electricity through a circuit when it is pressed or moved. Is a set of instructions that tell a computer what to do. Produces a small rapid back and forth motion. Is a small programmable computer.
5. Motor: Can be set to a precise angular position. Detects when there is or is not motion. Senses angular position. Produces rotating motion.
6. Potentiometer: Is a small programmable computer. Produces rotating motion. Senses angular position. Changes electrical signals into sound.
7. Servo: Can be set to a precise angular position. Creates light. Changes electrical signals into sound. Senses angular position.
8. Temperature sensor: Detects pressure or force. Detects heat. Heats or cools objects. Starts or stops the flow of electricity through a circuit when it is pressed or moved.
9. Vibration motor: Produces a small rapid back and forth motion. Detects pressure or force. Can be set to a precise angular position. Starts or stops the flow of electricity through a circuit when it is pressed or moved.

Table 8.3: Multiple choice hardware component definition items.

Alongside these multiple choice items, we also designed and coded an open-ended knowledge question to measure student understanding of robotic systems and components. 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. The video error codes resulted from district-level network restrictions that prevented the videos from playing within our online surveys early in our evaluation. 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. Because of strong positive results seen on this item during the Pioneers study (reported in chapter 9 and shown in figure 9.1) and the need to reduce the overall time requirement for the surveys, we did not include this item in the later Arts & Bots Math-Science Partnership survey.

Attitudes Scale Development Method

The last student evaluation tool we developed is meant to assess student attitudes with respect to technology. The majority of these items are components of a new and custom attitude scale, which we named the Robotics Activities Attitudes Scale. Our ultimate goal developing this scale was to create a valid and reliable tool for evaluating the effectiveness of creative robotics programs. We were particularly interested in measuring changes to middle school student attitudes towards technology and robotics. Validity and reliability are interrelated but separate properties of measurement.[7] The reliability of a measurement reflects the “permanent effects that persist from sample to sample,” and is inclusive of both the stability of a

[7] Kerrie Anna Douglas and Şenay Purzer. Validity: Meaning and relevancy in assessment for engineering education research. *Journal of Engineering Education*, 104(2):108–118, 2015; and Richard G Netemeyer, William O Bearden, and Subhash Sharma. *Scaling procedures: Issues and applications*. Sage Publications, 2003

subject's of scores over time and the internal consistency of items.[8] The validity of a measure refers to how well it actually measures the intended construct.[9] Our work was informed by the process for developing valid and reliable scales for evaluating psychological constructs, as recommended by Netemeyer, Bearden, and Sharma [2003]. This process takes a four step approach:

[8] Richard G Netemeyer, William O Bearden, and Subhash Sharma. *Scaling procedures: Issues and applications*. Sage Publications, 2003

[9] Richard G Netemeyer, William O Bearden, and Subhash Sharma. *Scaling procedures: Issues and applications*. Sage Publications, 2003

1. Construct Definition and Content Domain
2. Generating and Judging Measurement Items
3. Designing and Conducting Studies to Refine the Scale
4. Finalizing the Scale

We present, in the remainder of this chapter our development process for the student attitude scale We begin with our initial construct definitions and the items we generated to measure this in our early work in 2010. We then present our analysis and refinement to this scale following an initial study from 2010 to 2012. Data collected during this initial study was then used to inform a further revision to the survey in 2012. Data was collected using this new scale during a 2012 to 2014 study. The most recent version of the survey was developed following further analysis in 2015. We conclude this section with an exploratory factor analysis of data collected using this 2015 version of the scale.

Construct Definition and Related Works

Our goal in creating our Robotics Activities Attitudes Scale (RAAS) was to provide extracurricular and in school robotics programs a means for evaluating their effectiveness. Despite the overarching intent of these robotics programs to improve student Technological Fluency, we focused more specifically on the evaluation of students attitudes towards robotics activities for two main reasons. First, we believe that changes in attitudes towards robotics are the first sign that a student us prepared for continued motivation, participation, and interest in robotics and, more broadly, STEM activities. Second, we expect that short-duration interdisciplinary activities will have measurable impacts on student localized attitudes toward robotics. However, more generalized student attitudes towards technology, as a component of Technological Fluency, are slow to change, and students will need repeated engagement before these shifts are large enough to be measurable. It is important to measure localized attitude changes towards robotics early in the program in order to inform the development and refinement of program instruction. By providing this formative feedback to robotics programs, it is possible to check progress towards the goal of attracting students to STEM.

Table 8.4: Definitions of the Hypothesized Dimensions of Student Attitudes towards Robotics with Sources

Dimension	Definition	Sources
Interest	A student's positive feelings towards robotics activities and positive affect about robotics and technology more generally.	Bathgate et al. [2014], Science Learning Activation Lab [2010]
Expectancy Value	A combination of a student's expectancy and value of robotics tasks, this includes highly valuing robotics tasks and having confidence in one's own ability to successfully complete that task.	Bathgate et al. [2014], Science Learning Activation Lab [2010]
Curiosity	A student's motivation to seek understanding about robotics and technology, investigate new ideas, and excitement towards learning about new concepts involved in robotics and technology.	Bathgate et al. [2014], Science Learning Activation Lab [2010]
Confidence	A student's confidence in using technological tools and in completing robotics tasks, i.e.how well a student believes they can complete a robotics project.	Mercier et al. [2006]
Behavior	A student's intentions of participating in robotics and technology activities in the future.	Siegel and Ranney [2003], Weinburgh and Steele [2000]
Relevance and Perceived Value	A student's belief that the robotics activities have value in and relevance to everyday life.	Siegel and Ranney [2003]
Social Motivation	A student's motivation related to their desire to use robotics to help people and society.	Hypothesized, original dimension

During the development of our creative robotics program, Arts & Bots, investigation of related works did not uncover a validated scale for assessing student attitudes for robotics activities; however, scales existed for a variety of related constructs such as attitudes towards engineering, motivation toward science, and attitudes towards robots.[10] Notice that the focus of the RAAS is attitudes

[10] Emily Hamner and Jennifer Cross. Arts & Bots: Techniques for distributing a STEAM robotics program through K-12 classrooms. In *Proceedings of the Third IEEE Integrated STEM Education Conference, Princeton, NJ, USA*, 2013; and Jennifer Cross, Emily Hamner, Christopher Bartley, and Illah Nourbakhsh. Arts & Bots: Application and outcomes of a secondary school robotics program. In *Proceedings of the 2015 IEEE Frontiers in Education (FIE) Conference*, 2015

towards robotics activities, specifically the creation and development of robots as a subset of technological fluency. This is distinguished from existing scales for evaluating attitudes towards robots, which focus on a person's attitudes towards robots, as a consumer of completed devices.[11]

[11] Christoph Bartneck, E Croft, and D Kulic. Measuring the anthropomorphism, animacy, likeability, perceived intelligence and perceived safety of robots. In *Metrics for HRI Workshop*, volume 471, pages 37–44, 2008; and Tatsuya Nomura, Takayuki Kanda, Tomohiro Suzuki, and Kennsuke Kato. Psychology in human-robot communication: An attempt through investigation of negative attitudes and anxiety toward robots. In *2004 IEEE International Workshop on Robot and Human Interactive Communication (ROMAN)*, pages 35–40. IEEE, 2004

A number of scales have also been created for assessing student attitudes towards engineering. Besterfield-Sacre, Atman, and Shuman [1998] developed one such scale measuring undergraduate attitudes towards engineering.[12] This scale included measures of both student attitudes and student self-assessments in engineering. Some engineering attitudes scales were also developed for middle school students.[13] While these were closely related to the tool that we sought to develop, the focus on general engineering was overly broad for our purposes. Their scales for attitudes towards engineering included: interest (both in stereotypical and non-stereotypical aspects of engineering), positive opinions, negative opinions, problem solving, technical skills, and additional items.

[12] Mary Besterfield-Sacre, Cynthia J Atman, and Larry J Shuman. Engineering student attitudes assessment. *Journal of Engineering Education*, 87(2): 133, 1998

[13] Siobhán J Gibbons, Linda S Hirsch, Howard Kimmel, Ronald Rockland, and Joel Bloom. Middle school students' attitudes to and knowledge about engineering. In *International Conference on Engineering Education*, Gainesville, FL, 2004

Finally, Bathgate and colleagues, from the Learning Activation Lab, developed a tool for assessing student motivation in science.[14] They associate the concept of student motivation in STEM as being a critical component in a student's future engagement and participation in science and STEM. The 89 items of their scales were distributed between dimensions of context (formal or informal), manner of interaction, science topic, and motivation dimensions. They defined motivation towards science as having the following dimensions: appreciation, curiosity, identity, interest, persistence, responsibility, and expectancy value. This, as it most closely invokes our interests, was the basis for many of our scales for attitudes towards robotics activities.

[14] Meghan E Bathgate, Christian D Schunn, and Richard Correnti. Children's motivation toward science across contexts, manner of interaction, and topic. *Science Education*, 98(2):189–215, 2014; and Science Learning Activation Lab. Activated science learner: Technical report for surveys 1.1-5.0, 2010

From this related research, we hypothesized seven base scale definitions that represent the dimensions of student attitudes towards robotics: *Interest*, *Expectancy Value*, *Curiosity*, *Confidence*, *Behavior*, *Relevance & Perceived Value*, and *Social Motivation*. Please refer to table 8.4 for the definitions of these dimensions and the item sources used for each dimension.

Generating Measurement Items for RAAS

For our seven dimensions of student attitudes towards technology, items forming the interest, expectancy value, and curiosity scales were primarily adapted from the "Activated Science Learner: Technical Report for Surveys 1.1-5.0."citeactlab2010 This was a precursor to Bathgate, Schunn, and Correnti [2014], which provides items evaluating attitudes of six science topics: astronomy, biology, earth science, engineering, physical science, and general science. We adapted these topics to align with our focus on robotics and technology. Terms related to other topics were modified to read: robots, robotics, technology, and computers. We chose to include questions related to technology and computers, to provide greater variety between items and reduce response fatigue, and because we considered technology and computers to be closely related to robotics activities, as most such activities include similar tasks. The confidence scale also utilized some items from a scale developed to evaluate perception of oneself as a computer user, which were adapted to reference robots.[15]

[15] Emma M Mercier, Brigid Barron, and KM O'Connor. Images of self and others as computer users: The role of gender and experience. *Journal of Computer Assisted Learning*, 22(5):335–348, 2006; and Debra Lynn Bernstein. *Developing Technological Fluency through Creative Robotics*. PhD thesis, University of Pittsburgh, 2010

The final attitudes scale had questions that were distributed among dimensions as follows: interest (12 items), expectancy value (10 items), curiosity (8 items), confidence (3 items), behavior (3 items), perceived value and relevance (5 items), social motivation (2 items), and other (1 item). Table 8.5 lists all of the items that are in each dimension used in the 2010 version of the RAAS. The items were constructed as 44 Likert-like scale items where students stated their agreement with various statements on scale consisting of "NO!" "no," "neither yes or no," "yes," and "YES!"[16] which we scored with a 1 to 5 scoring where 1 was "NO!" and 5 was "YES!"

[16] Siobhán J Gibbons, Linda S Hirsch, Howard Kimmel, Ronald Rockland, and Joel Bloom. Middle school students' attitudes to and knowledge about engineering. In *International Conference on Engineering Education*, Gainesville, FL, 2004

Piloting RAAS 2010

During the 2010/2011 and 2011/2012 academic years, three teachers implemented, Arts & Bots, with their classes, collecting survey data using RAAS 2010 both pre- and post- project. The first teacher had 30 students in a technology class complete the pre-test survey in

Table 8.5: Items included in the RAAS 2010 by sub-scale

Interest
1. I would like to learn more about robots.
2. Computers are interesting to me.
3. Topics like robots just don't grab my interest.
4. Robots are interesting to me.
5. I use the Internet to find information about computers.
6. I like to watch TV shows and/or read about robots.
7. I try to do activities related to computers.
8. I like to explore computers.
9. I like to do robotics activities.
10. I feel good when I learn about computers.
11. Robots are boring to me.
12. I have a good feeling about computers.
Expectancy Value
1. I want to learn everything about computers, even if it is complicated
2. Learning about robots is important to me.
3. I know I can learn a lot about robots.
4. If I started a robotics project, I think I could do a really good job.
5. I'm afraid I won't be able to do a good job on a project about computers.
6. It's important to me to know more about computers than most people.
7. When I don't know something about computers, I try and find an answer.
8. I ask a lot of questions about computers if I don't understand them.
9. I like to prove that I know more about robots than my friends.
10. I like to learn new facts about robots.
Curiosity
1. I am curious about robots.
2. I am interested in discovering things about computers.
3. I get excited about discussing computers.
4. It is cool to learn new things about robots.
5. I enjoy exploring new ideas about computers.
6. I look for as much information as I can about robots.
7. Everywhere I go, I am out looking for new things about robots.
8. I am often trying to find out more about computers.
Confidence
1. I feel confident about my ability to make robots.
2. I am the kind of person who is good at making robots.
3. I am not good at making robots.
Behavior
1. I plan to take more robotics or computer classes at school.
2. I plan to sign up for robotics or computer activities outside of school.
3. I plan to build my own robot.
Relevance and Perceived Value
1. Robots have nothing to do with my life outside of school.
2. Learning about robots will help me understand how everyday things work.
3. Learning about computers is not important for my future success.
4. Most people should learn about robots.
5. It is important to know about computers in order to get a good job.
Other
1. I wish I had robot-building materials at home.
Social Motivation
1. I want to help other people understand computers.
2. I want to use robots to help solve people's problems.

November 2010, and the post-test survey in May 2011. The second teacher had 15 students in a history class complete the pre-test survey in February 2011, and the post-test survey in March 2011. The third teacher had 10 students in an anatomy class complete the pre-test survey in December 2011, and the post-test survey in January 2012. Together, the classes provided pilot evaluation data for a total of 56 students. To avoid double counting, we limited analysis of results from the students' pre-surveys. We scored student responses to each item on a scale from 1 to 5. Negatively worded items were recoded in reverse, with 5 representing the strong disagreement of "NO!"

To construct dimensions with internal reliability, we first evaluated the Cronbach's Alpha of each sub-scale. The shorter of the item sub-scales (Confidence, Behavior, Social Motivation, and Perceived Value) did not have enough items to test for internal reliability. The Expectancy Value scale had an acceptable Cronbach's Alpha of .764 with 10 items. This scale included the question "I'm afraid I won't be able to do a good job on a project about computers" that had a notable negative impact on the reliability, and if removed, the Cronbach's alpha jumped to .799. This indicated a poor match between this item and the rest of the scale, which we suspect was caused by the confusing presence of two negative words: "afraid" and "won't." The Interest subscale had an excellent Cronbach's Alpha of .860 with 12 items. The Curiosity subscale also had an excellent Cronbach's Alpha of .871 with 8 items.

We also performed an exploratory factor analysis on the three larger dimensions (Curiosity, Interest, and Expectancy Value) to test if the scales developed were univariate. Reversed or negative items were excluded from this analysis since negative items most frequently correlate best with other negative items and serve the separate purpose of checking participant reading accuracy. For example, the items, "Robots are interesting to me," and "Robots are boring to me," are unlikely to form a single factor — despite obvious similarities — but do allow researchers to check for haphazard participant responses. Exploratory Factor Analysis was performed using

SPSS using the Maximum Likelihood fitting procedure and Promax oblique rotation method. From the Expectancy Value subscale, three factors were extracted using an eigenvalue threshold of 1, and checking the Scree plot for additional relevant factors. The first two factors accounted for 56.1% of variance of the scale, and had weighting that cleanly divided the items between those that used the word "robotics" or "robots" as the subject and those that used the word "computer." The item: "I ask a lot of questions about computers if I don't understand them" was the only item in the third factor.

The items of the Curiosity dimension split into two factors accounting for 65.8% of variance. The two factors again seperated the four "robot" items from the four "computer" items. We also see this trend in the Interest dimension, which divided into two factors accounting for 59.2% of variance: one containing four "robot" and the other containing six "computer" questions.

Creation of RAAS 2012

Our piloting of the RAAS 2010 highlighted two major areas for revision. We saw that it was not feasible to test reliability using Cronbach's alpha on the scales that have 5 or fewer items: Confidence, Behavior, Social Motivation, and Perceived Value, and thus we could not generate generalizable conclusions for the cumulative scores on these scales. We reformulated and combined these domains to create the new "Confidence and Identity" dimension comprised of nine items.

Additionally, we saw that all three of our factors with more than five items, Expectancy Value, Interest, and Curiosity, were not univariate and instead produced at least two factors each through exploratory factor analysis. The items that had been adapted to have "robots" or "robotics" as the item topic formed one factor within each dimension; those adapted to include the word "computer" formed a second factor. This prompted a refinement of the wording choices we used to adapt the items from the original sources.

Looking back at the items as developed by Bathgate et al. [2014],

Table 8.6: Items Included in the RAAS 2012 by sub-scale

Interest
1. I would like to learn more about robotics.
2. Technology is interesting to me.
3. Robotics is interesting to me.
4. I like to watch TV shows and/or read about robots.
5. I try to do activities related to technology.
6. I like to do robotics activities.
7. I feel good when I learn about technology.
8. Robots are boring to me.
9. I have a good feeling about computers.
Expectancy Value
1. I want to learn everything about technology, even if it's complicated.
2. Learning about robots is important to me.
3. I know I can learn a lot about robots.
4. If I started a robotics project, I think I could do a really good job.
5. It's important to me to know more about technology than most people.
6. When I don't know something about computers, I try and find an answer.
7. I ask a lot of questions about robots if I don't understand them.
8. I like to prove that I know more about technology than my friends.
9. I like to learn new facts about robots.
Curiosity
1. I am curious about how robots work.
2. I am interested in discovering things about robots.
3. I get excited about discussing technology.
4. It is cool to learn new things about robots.
5. I enjoy exploring new ideas about robotics.
6. I look for as much information as I can about robots.
7. Everywhere I go, I am out looking for new things about robots.
8. I am often trying to find out more about computers.
Confidence and Identity
1. I am curious about how robots work.
1. I feel confident about my ability to make robots.
2. I am the kind of person who works well with technology.
3. I am not good at making robots.
4. Whenever I use something that is computerized, I am afraid I will break it.
5. I feel uncomfortable when someone talks to me about technology.
6. I am a technical type person.
7. Other people think of me as a technical type person.
8. It makes me nervous to even think about using computers.
9. I am the type of person who could become a roboticist.

we noticed that we had failed to take into account the hierarchy or generality of the topic of each item.[17] We hypothesized that this played an important role in how our dimensions were interpreted by students. Further, we realized that our items may be suffering from an expert blind spot where we, as robotics researchers and educators, are prone to seeing the inherent relationship between robotics and computers. Students piloting our survey clearly demonstrated internal, conceptual separations of robots and computers.

[17] Meghan E Bathgate, Christian D Schunn, and Richard Correnti. Children's motivation toward science across contexts, manner of interaction, and topic. *Science Education*, 98(2):189–215, 2014

We reviewed each source item in its original form in order to better match the source items in terms of level of abstraction. In this way, we matched general concepts like "science" to "technology," more specific ideas of a discipline like "biology" to "robotics," and very concrete topics like, "animals" to "robots." We also removed items that either negatively impacted the Cronbach's alpha or contributed very little, in order to reduce the overall length of RAAS. As seen in table 8.6, the resulting modified subscales for attitudes towards robotics activities, RAAS 2012, consisted of four balanced-length subscales. This reduced the number of Likert-type items from 44 to 36, and reduced the number of computer-specific questions from 15 to 5.

Factor Description	Example Items	Variance
Personal Robotics Identity	Everywhere I go, I am out looking for new things about robots. I am the type of person who could become a roboticist.	6.4%
Interest in Learning about Robotics	It is cool to learn new things about robots. Robotics is interesting to me.	52.2%
Interest in Learning about Technology	I am often trying to find out more about computers I get excited about discussing technology.	5.2%
Confidence with Technology	It makes me nervous to even think about using computers. (negative) I have a good feeling about computers.	3.7%

Table 8.7: Factors from RAAS 2012 Exploratory Factor Analysis

Piloting RAAS 2012

Between 2012 and 2014, nine additional seventh and eighth grade classes, taught by six teachers, participated in Arts & Bots. Students in these classes took the RAAS 2012 both before and after their projects. To avoid double counting students, we only used the students' pre-survey data in this analysis. Within these nine classes, we collected data from 159 pre surveys.

We again evaluated the internal consistency of the scales using Cronbach's alpha. The 8 item scale for Curiosity had an alpha of .926 reflecting excellent internal consistency. The 9 item Interest scale had excellent internal consistency with Cronbach's alpha equal to .929. The 9 item Confidence scale had good internal consistency and Cronbach's alpha of .846. Finally, the Expectancy Value scale had 9 items and a good alpha of .891.

We again performed an exploratory factor analysis on the complete 35 item scale to explore how items correlated with one another compared to our four expected dimensions. This Exploratory Factor Analysis was performed in SPSS using the Maximum Likelihood fitting procedure and Promax oblique rotation method. We extracted factors based on an eigenvalue threshold of 1 and checking the Scree plot for additional relevant factors. Using these methods, we identified four factors that accounted for 67.5% of scale variance. However, these factors were not explicitly divided into the dimensions that we hypothesized. Instead, we found the following four factors: Personal Robotics Identity, Interest in Learning about Robotics, Interest in Learning about Technology, and Confidence with Technology. These factors are described in table 8.7 with example items. We used these factors to help inform the creation and removal of items to create the RAAS 2015.

Creation of RAAS 2015

Our analysis of the RAAS 2012 scale primarily highlighted problems with the Confidence and Identity scale as well as issues with how secondary dimensions were distributed. While the four main constructs of RAAS 2012 were Curiosity, Expectancy Value, Interest, and Confidence & Identity; secondary item features such as subject (technology versus robotics versus robots) and negative structure (i.e. reversed items) were non-uniformly distributed among the primary

Activity Aspect	New Items
Programming Confidence	Capacity: "I can write a computer program" Capacity: "I can program a robot" Future: "I could learn to write a computer program"
Robot Building Confidence	Capacity: "I can make a robot" Skill: "I could learn to build a robot" Future: "I could learn to build a robot"
Engineering Design	Skill: "I am good at designing things" Appreciation: "I come up with solutions that other people don't think of" Enjoyment: "I like designing new things"
Computational Thinking	Skill: "I am good at thinking logically" Application: "I solve problems logically" Enjoyment: "I like solving complex problems"
Teamwork	Skill: "I am a good team member" Capacity: "I can communicate my ideas to my team" Enjoyment: "I like working on teams"

Table 8.8: Item added to the 2012 RAAS to Create the 2015 RAAS

dimensions and were influential in how items were grouped in our exploratory factor analysis. The subjects of the 35 RAAS 2012 items were: 8 robots, 5 computer, 11 robotics, and 11 technology. Five items were reversed.

The 9 items in the Identity & Confidence scale were disproportionately negative (i.e., 4 of the 5 negative items in the RAAS 2012 were Identity and Confidence items), and a disproportionate number of the items had general technology or computers as the subjects (i.e. only 3 items had robotics or robots as the subject).

We saw the impact of this in the Exploratory Factor Analysis of the 35 items, which, again, presented four factors: Personal Robotics Identity, Interest in Learning about Robotics, Interest in Learning about Technology, and Confidence with Technology. The complementary factors of Interest in Learning about Robotics and Interest in Learning about Technology drew attention to the interrelationship between our Curiosity and Interest constructs and again highlighted the distinction between "robotics" and "technology and computers" as conceptualized by middle school students. However, the Confidence with Technology factor did not have a complementary Confidence with Robotics factor, which prompted us to work to strengthen and balance the Confidence and Identity scale with additional items focused on robots or robotics.

We also found that nearly all the items that were associated with robots and robotics were generalized, such as "Robotics is interesting to me," and did not mention the specific activities involved in robotics projects. We systematically generated new items related to five aspects of robotics activities: Programming, Robot Building, Computational Thinking, Engineering Design Process, and Teamwork. Within these aspects we generated five types of items: Capacity, where students assessed their ability to complete an action; Skill, where students evaluated the quality of their skills; Application, where students rated if they perform certain actions; Enjoyment, where students rated their enjoyment of the action; and Future, where students assessed their ability to learn to do the action. The Capacity, Application, Future, and Skill items were all created to strengthen the Confidence and Identity dimension. The Enjoyment items were added to the Interest dimension. Teamwork items were not included in the Confidence and Identity and Interest dimensions. They comprise their own separate subject.

Piloting RAAS 2015

In 2015 and 2016, ten classes taught by ten teachers participated in Arts & Bots. Students in these classes took the RAAS 2015 both before and after their projects. In order to avoid double counting students, we only analyzed the students' pre-survey data. From these 10 classes, we collected data from 242 student pres-urveys. Six students did not complete all the sections of the survey, and so their data is excluded when items they missed were part of the analysis. Teamwork items were not included in the scale analysis, as they were not part of the four main construct domains.

Using the data from the 2015 to 2016 study, we again evaluated the internal consistency of the scales using Cronbach's alpha. The 8 item scale for Curiosity had an alpha of .918 reflecting excellent internal consistency. The 11 item Interest scale also had excellent internal consistency with a Cronbach's alpha equal to .921. The 19 item Confidence scale had an excellent internal consistency and a

Cronbach's alpha of .918. Finally, the Expectancy Value scale had 9 items and a good alpha of .879.

We performed an exploratory factor analysis on the RAAS 2015. We excluded reversed or negative items as they frequently form their own factors. We also excluded the teamwork items which are related to a completely separate aspect of robotics activities. Exploratory Factor Analysis was performed using SPSS using the Maximum Likelihood fitting procedure and Promax oblique rotation method. We extracted 5 factors following the guidelines of using an eigenvalue threshold of 1 and evaluating the Scree plot, which accounted for 66.2% of scale variance. The 5 factors were: Confidence, Learning Potential, Personal Robotics Identity, Personal Technology Identity, and Curiosity.

Two of the factors that we extracted matched dimensions that we had constructed. The Confidence factor included items encompassing confidence related to skills involving robots, computers, and problem solving (see table 8.9). The Curiosity factor included items that measured a student's feelings towards discovering, exploring, and learning about new robotics and technology concepts.

Two other factors were related to the student's personal identity. The Personal Robotics Identity factor included interest, identity, expectancy value, and strongly worded curiosity items that reflected the broader importance of robotics to everyday life. Similarly, the Personal Technology Identity factor included interest, identity, curiosity, and expectancy value items that measured the broader importance of technology and computers to everyday life.

The final factor, Learning Potential, was fascinating in that it included interest, confidence, curiosity, and expectancy-value items. These items all related to a student's confidence in their ability to develop new skills and gaining knowledge. This factor is distinct from the dimensions that we originally developed for RAAS 2010, but is also intriguing. It seems to be related to other research which has demonstrated that a student's belief that "intelligence is malleable," sometimes referred to as having a Growth Mindset, has positive implications for student motivation and resilience.[18]

[18] Lisa S Blackwell, Kali H Trzesniewski, and Carol Sorich Dweck. Implicit theories of intelligence predict achievement across an adolescent transition: A longitudinal study and an intervention. *Child Development*, 78(1):246–263, 2007; and Carol S Dweck. Even geniuses work hard. *Educational Leadership*, 68(1):16–20, 2010

Table 8.9: RAAS 2015 Factors

Confidence
1. I am good at making robots.
2. I can program a robot.
3. I can write a computer program.
4. I can make a robot.
5. I am good at thinking logically.
6. I feel confident about my ability to make robots.
7. I like solving complex problems.
8. I am good at designing things.
9. I solve problems logically.
10. I could learn to write a computer program.
Learning Potential
1. If I started a robotics project, I think I could do a really good job.
2. I could learn to build a robot.
3. I like designing new things.
4. I would like to learn more about robotics.
5. I feel good when I learn about technology.
6. I like to learn new facts about robots.
7. I get excited about discussing technology.
8. I like to do robotics activities.
9. I know I can learn a lot about robots.
10. I ask a lot of questions about robots if I don't understand them.
Personal Technology Identity
1. Other people think of me as a technical type person.
2. I try to do activities related to technology.
3. I am a technical type person.
4. When I don't know something about computers, I try and find an answer.
5. I am often trying to find out more about computers.
6. I am the kind of person who works well with technology.
7. I like to prove that I know more about technology than my friends.
8. Technology is interesting to me.
9. I have a good feeling about computers.
10. I come up with solutions that other people don't think of.
Personal Robotics Identity
1. Everywhere I go, I am out looking for new things about robots.
2. I like to watch TV shows and/or read about robots.
3. I am the type of person who could become a roboticist.
4. I look for as much information as I can about robots.
5. Learning about robots is important is important to me.
6. It's important to me to know more about technology than most people.
Curiosity
1. It is cool to learn new things about robots.
2. I am curious about how robots work.
3. I enjoy exploring new ideas about robotics.
4. Robotics is interesting to me.
5. I am interested in discovering things about robots.
6. I want to learn everything about technology, even if it's complicated.

Perceptions of STEM Careers

While not directly related to the instruction or primary goals of the Arts & Bots program, we decided to include two scales related to student perceptions of STEM careers as an exploratory evaluation of the Arts & Bots Math-Science Partnership. The first scale was developed by the Engineering is Elementary team for measuring elementary school student knowledge of the work of engineers, as well as naive conceptions about engineering.[19] Through the recommendation of the scale authors, and review of their raw pilot data, we refined their 37-item scale for our age group, by creating a modified scale from the 14 most difficult items from their testing. The items are provided as simple yes-or-no questions, which are scored based on average responses collected from professional engineers. The resulting 14-item scale is below:

[19] Cathy P Lachapelle, Preeya Phadnis, Jonathan Hertel, and Christine M Cunningham. What is engineering? a survey of elementary students. *2nd P-12 Engineering and Design Education Research Summit*, 2012

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

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

The second scale, the STEM Semantic Survey, was developed by Christensen et al. [2014], and measures student perceptions and dispositions towards technology, engineering and STEM careers.[20] The semantic survey also included subscales for math and science perceptions, which we omitted in the interest of participant time. The students rate their dispositions along 5 dimensions, defined by dichotomies on a scale from 1 to 7, as shown in table 8.10. We recoded this data during analysis such that: 1 represents the "negative" side of the dichotomy and 7 is "positive."

[20] Rhonda Christensen, Gerald Knezek, and Tandra Tyler-Wood. Student perceptions of science, technology, engineering and mathematics (STEM) content and careers. *Computers in human behavior*, 34:173–186, 2014

Choose one circle between each adjective pair to indicate how you feel about the object. (value from 1 to 7)
To me, ENGINEERING is: appealing - unappealing fascinating - mundane means nothing- means a lot exciting - unexciting boring - interesting
To me, TECHNOLOGY is: appealing - unappealing means nothing - means a lot boring - interesting exciting - unexciting fascinating - mundane
To me, a CAREER in science, technology, engineering, or mathematics (is): means nothing - means a lot boring - interesting exciting - unexciting fascinating - mundane appealing - unappealing

Table 8.10: STEM Semantic Survey

The instruments described above were used to inform and evaluate the Arts & Bots program. These scales address our research questions and allow us to collect student data on students experiences during Arts & Bots, student technical knowledge, and student attitudes towards technology. As the Arts & Bots continues, we aim to eventually reduce the total number of survey items to decrease the amount of class time consumed to complete research tasks. In chapter 9, we describe the resulting student data and our analysis.

9
Analyzing Student Outcomes from Projects

Outcomes from the Arts & Bots Pioneers Study

Here, we present data and analysis from the Arts & Bots Pioneers study which took place between 2010 and 2014. Data were collected from six schools: five public and one independent, and a mix of rural (n=3), suburban (n=2), and urban (n=1). Data were collected in 13 separate classes. These 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 that follow 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 wordin, and so, items that were introduced more recently may have fewer responses.

The analysis in this chapter 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

Portions of this section first appeared in:

Cross, J. L., Hamner, E., Bartley, C., & Nourbakhsh, I. (2015). Arts & Bots: application and outcomes of a secondary school robotics program. In 2015 IEEE Frontiers in Education Conference (FIE).

Hamner, E., Zito, L., Cross, J., Slezak, B., Mellon, S., Harapko, H., & Welter, M. (2016). Utilizing engineering to teach non-technical disciplines: case studies of robotics within middle school English and health classes. In 2016 IEEE Frontiers in Education Conference (FIE).

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 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.

Analysis

Students were assigned unique subject numbers, and names were replaced by these 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 to 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 9.1). 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 9.2), “Did you enjoy doing this project?” (table 9.3), “How did this experience change how you think about technology?” (table 9.4), and, “Should other students have this experience?” (table 9.5).

Attitude Scales (RAAS prototype items): 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!”

Open-Ended Questions	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

Table 9.1: Inter-rater reliabilities for open-ended questions

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: that the percent of students responding positively on the pre-test was different from that on the post-test. This data was collected before the finalization of the RAAS scales in 2015 (chapter 8), so data was treated item-wise and not combined into sub-scales.

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: that the distribution of the student scores was different between the pre-test and post-test. The score distribution was asymmetrical with the number of students achieving a maximum score on the evaluation preventing 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.

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

Technological Fluency

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 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

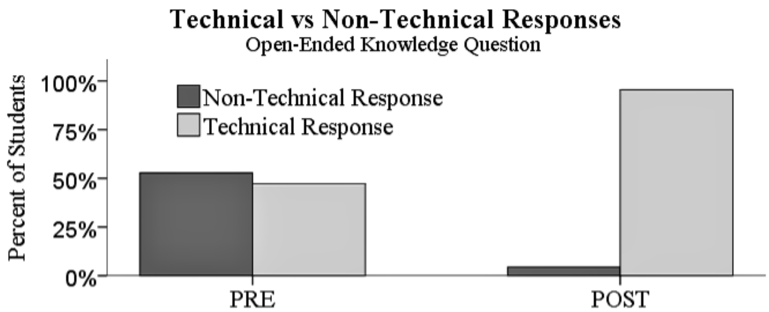

Figure 9.1: Percent of students giving non-technical and technical responses on the open-ended knowledge question: "What parts did Evan use to make the flower?" (N=89).

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. Correct technical answers that were misspelled were coded as correct. Some students were unable to play the video on school computers in either the pre- or the post-survey, and were excluded from analysis (N=26), resulting in the smaller sample size (N=89). 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 (figure 9.1) 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 (figure 9.2). 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.

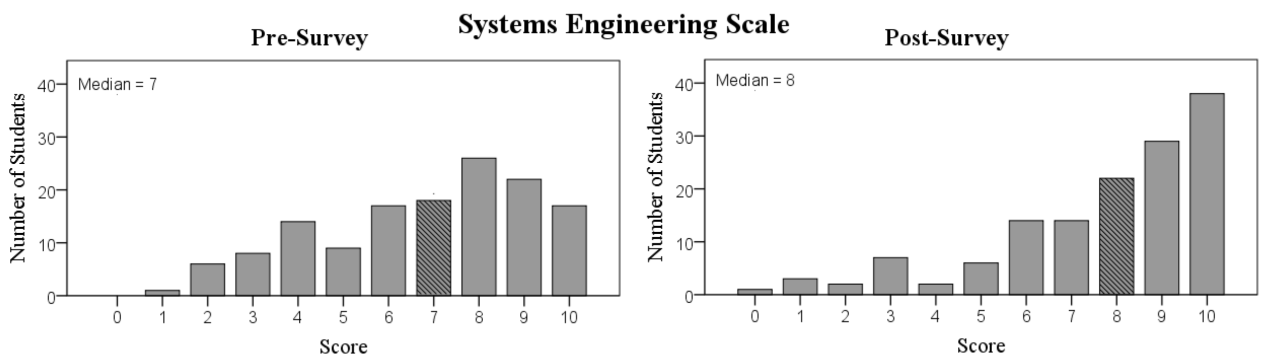

Figure 9.2: Distribution of student scores on the 10 item Systems Engineering Scale from Art & Bots Pioneers, median score bar indicated. (N=138)

For two attitude Likert-type questions related to learning technical knowledge, there were significant differences found between the pre- and post-survey responses. For 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 of technology, we hypothesize that for some students, the project was enough to fulfill 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 introducing Arts & Bots to students as a merely fragment of that field in order to seed new curiosity.

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

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%

Table 9.2: "What was the best thing that you learned during the project?" Response Summary (Categories representing less than 4.5% of students not shown.)

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, as well as by short answer responses described below.[1]

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, one student wrote, "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 (e.g., "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, the experience also resulted in a shift in identity for some students 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."

[1] Debra Lynn Bernstein. *Developing Technological Fluency through Creative Robotics*. PhD thesis, University of Pittsburgh, 2010

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). Harder than expected 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 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. In the words of one student: "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). That 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. This metric 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

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%

Table 9.3: "Did you enjoy doing this project? Why or why not?" Response Summary (Categories representing less than 4.5% of students not shown.)

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 another conveyed that, "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 our hypothesis regarding 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?" One student stated, "Poetry can be very difficult to understand, but using robotics and

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%

Table 9.4: "How did this experience change how you think about technology?" Response Summary (Categories representing less than 4.5% of students not shown.)

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 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. 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

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%

Table 9.5: ”Should other students have this experience? Why or why not?” Response Summary (Categories representing less than 4.5% of students not shown.)

the larger world around them, students came to see that technology could have creative applications, and they appreciated the future benefits of what they had learned.

Complementary Non-Technical Skills

Teamwork - Beyond the primary goal of improving student technological fluency, we also saw evidence of students developing non-technical skills. One of the most prominentof these 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). 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. As a response to, “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 savy[sic] 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 (χ^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, such as: "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 also 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. 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 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.

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. An example of this sort of response is: "[...] 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.

Outcomes from the Arts & Bots MSP Study

In this section, we present data and analysis from the Arts & Bots Math-Science Partnership study, which took place between 2014 and 2017. Data were collected from two school districts: one suburban district in two schools and one rural school district in six schools.

Data were collected in 43 separate class project implementations. The suburban school had 322 unique student participants and the rural school district had 454 unique student participants. Participants included 406 sixth graders, 293 seventh graders and 226 eighth graders. These counts are not unique students, as 264 students participated in more than one project across grade levels. Only data collected during their first Arts & Bots projects were included for consistency, unless otherwise noted.

As in the Pioneer study, the number of students in the data samples below varies slightly due to a number of factors. Student absentees resulted in unequal numbers of surveys, and incomplete data collection by teachers led to students only completing pre- or post-surveys. Some students completed their surveys on paper instead of online. The additional time needed for digitizing these surveys impacted the availability of some data collected in the 2016-17 academic year. Finally, our survey tools undergo regular refinement and modification of wording, thus items that were introduced more recently may have fewer responses.

Short Answer Responses

In their short answer survey responses, coded as described in chapter 8, 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. No limit was provided regarding the number of codes that could be assigned to each student response. This resulted in the total number of codes (N_C) being larger than the total number of student responses (N_R).

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 (N_C=394). Responses assigned the code, "Fun and Enjoyment (General or Technology)" indicate that students expressed either the anticipation (pre-) or the reflection (post-) of liking aspects of the experience. This code was the most commonly assigned code for the question, "Did you enjoy this project?" (29.9%,

Code Description	**Percent Assigned**	
"Did you enjoy this project? Why or why not?"		N_R=274
Fun and Enjoyment (General or Technology)	29.9%	
Teamwork	19.7%	
Technical Learning	12.4%	
Multidisciplinary	10.6%	
Enjoy Building	8.0%	
Negative Teamwork	7.7%	
New, Novelty, Different	6.9%	
Vague Learning	5.5%	
"How did this experience change how you think about technology?"		N_R=309
Technical Learning	28.2%	
Fun and Enjoyment (general or technology)	17.5%	
Appreciation for the Complexity of Technology	12.9%	
No Change	12.6%	
Appreciation for the Broader Applicability of Technology	11.0%	
Easy or Less Challenging	6.5%	
"Should other students have this experience? Why or why not?"		N_R=274
Fun or Enjoyment (General or Technology)	26.3%	
Technical Learning	23.4%	
Vague Learning	16.1%	
My Career	12.4%	
Teamwork	10.2%	
Vague Positive	5.8%	
Students should be allowed to choose	5.1%	
"What was the best thing you learned?"		N_R=317
Technical Learning	62.8%	
Teamwork	21.1%	

Table 9.6: Percentage of student responses assigned each code by question (Categories representing less than 5% of students not shown.)

N_R=274), and, "Should other students have this experience?" (26.3% of responses, N_R=274). It was the second most commonly assigned code for the question, "How did this experience change how you think about technology?" (17.5% of responses). Another noteworthy code assignment refers to the enjoyment of the multidisciplinary or creative nature of the project (10.6%, , N_R=274, "Did you enjoy this project?"). For example one 8th grade student stated, "... I also liked that I got to interpret literature through technology."

Technical learning is also broadly reported by students, ranking as the first, second, or third most common response to each of the four questions (see table 9.6). This code indicates a response expressing any desire to learn about, or an increased understanding of robots, technology, electronics, programming, or computers. 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?" (N_R=274), and believe that others would learn something in 16.1% of responses to the question, "Should other students have this experience?" (N_R=274).

Positive teamwork experiences are the 2nd most frequent code for, "What was the best thing that you learned during the project?" (21.1% of responses, N_R=317) and, "Did you enjoy this project?" (19.7% of responses, N_R=274). 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%, N_R=274). It is worth noting that negative teamwork experiences are cited in 7.7% of responses to, "Did you enjoy this project?" (N_R=274), 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 (12.6%, N_R=309), several interesting changes are reported in response to the question, "How did this experience change how you think about technology?" An 8th grade student said, "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 12.9% (N_R=309) of student responses which express that this experience encouraged them to appreciate 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 about the difficulty, and so these responses were coded into a single category.

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, 11.0% (N_R=309) of student responses express a deeper 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 that 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 (N_R=274) were coded as "My Career". Overall students recommend Arts & Bots be offered to other students; 88.7% of codes

"How did this experience change how you think about technology?" N_R=308	**Male** N_R=149	**Female** N_R=159
Technical learning	26.8%	29.6%
Fun and Enjoyment (general or technology)	15.4%	19.5%
Appreciation for the complexity of technology	12.8%	13.2%
No Change	14.8%	10.7%
Appreciation for the broader applicability of technology	7.4%	13.8%
Easy or Less Challenging	4.7%	8.2%
Easier than I thought: Increased Confidence	3.4%	5.0%
"What was the best thing you learned?" N_R=316	**Male** N_R=153	**Female** N_R=163
Technical learning	60.8%	64.4%
Teamwork	21.6%	20.9%

Table 9.7: Percentage of student responses assigned each code by question and by gender (Categories representing less than 5% of students not shown.)

assigned are positive (N_C=355), 5.4% of codes assigned are mixed, and only 4.8% of codes assigned are negative.

By dividing the student responses by gender (see table 9.7), we were also able to examine differences between the responses of young men or women. While none of the differences proved to be significant (via Fischer's Exact Test), we saw a higher percentage of women responding to, "How did this experience change how you think about technology?" with an appreciation for the broader applicability of technology (13.8% vs 7.4% of men). Similarly, we saw more women reporting that they found technology to be easier to use than they expected (8.2% vs 4.7% of men). A larger percentage of men reported that the experience did not impact how they thought about technology (14.8% vs 10.7% of women).

When we look at how student responses change between their first and second Arts & Bots projects (see table 9.8), we also see differences one might anticipate. We see that students in their second experience are significantly more likely to respond to, "How did this experience change how you think about technology?" with a "no change" statement (Fischer's Exact Test, $p= 0.0084$) or a say that technology lacks novelty ($p=0.0192$). Perhaps most interestingly, we see a significantly higher percentage of students in their second experience citing the non-technical class content, or disciplinary learning, in response to, "What was the best thing you learned?" ($p<.0001$). For example, a seventh grader in a health and physical education class

"How did this experience change how you think about technology?"	**Exper. 1** N_R=309	**Exper. 2** N_R=94
Technical learning	28.2%	25.5%
No Change	12.6%	24.5%
Fun and Enjoyment (general or technology)	17.5%	11.7%
Appreciation for the complexity of technology	12.9%	8.5%
Appreciation for the broader applicability of technology	11.0%	8.5%
Vague Answer	3.6%	6.4%
Lack of novelty	1.0%	5.3%
Easy or Less Challenging	6.5%	5.3%
"What was the best thing you learned?"	**Exper. 1** N_R=317	**Exper. 2** N_R=91
Technical learning	62.8%	49.5%
Teamwork	21.1%	17.6%
Disciplinary learning	1.6%	13.2%
Didn't learn anything	2.2%	7.7%

Table 9.8: Percentage of student responses assigned each code by question and by experience number (Categories representing less than 5% of students not shown.)

said that the best thing they learned was, "The kinds of movement in the arm and how the muscles make it move."

10

Final Words

The purpose of this thesis was to answer two research questions through the development and consideration of the Arts & Bots program between 2010 and 2017. These research questions were:

- How can robotic systems be utilized in educational contexts to promote talent-based learning?
- What program elements are instrumental in creating talent-based educational robotic systems?

The Arts & Bots program is a middle school robotics program we created to be integrated into non-technical classes to support student development of technological fluency. Arts & Bots also enables non-technical teachers to identify their students' computational thinking talents and engineering design talents. Our answers to the research questions and our associated development work were thus founded on four hypotheses:

Identification Capacity We hypothesize that a non-technical teacher provided with talent identification-oriented professional development, and a customizable, creative technology system increases their confidence and efficacy in identifying diverse student talent.

Talent Demonstration We believe that creativity-oriented technologies can be used in educational contexts to provide students with opportunities to demonstrate a wide diversity of talents for teachers to identify.

Class Integration We hypothesize that teachers can integrate creative robotics into non-technical class content, allowing us to provide robotics experiences to a wide diversity of students.

Program Affordances We hypothesize that there exists a set of affordances in the Arts & Bots program that support talent-based learning, and in particular: classroom integration, student talent demonstration, and teacher identification capacity.

In this dissertation, we describe the development and evaluation of the Arts & Bots program, with a focus on refining it as a tool for identifying student talents, and evaluating the role of educational robotics in talent-based learning. The Arts & Bots program is more than just an education robotics tool; it is a complete educational intervention. The robotics tool, as presented, is just a small component of the program, which is supported by an equally important teacher training model, an understanding of classroom best practices, a custom programming environment that emphasizes integration with other disciplines, and our work to evaluate and document the rich ecosystem of this program. Each of these components is presented in one or more of chapters of this thesis, summarized hereafter. Much like Arts & Bots, each individual chapter is not a complete solution or answer to the research questions presented, but the program is, together, more than the sum of its parts.

- Chapter 4 presents the development of our teacher training model, and the final model as a contribution of the Arts & Bots program. This training plays a key role in enabling teachers to use Arts & Bots in a way that is consistent with the *Class Integration* and *Identification Capacity* hypotheses. The refinement the Arts & Bots training program, and our documentation of the requisite materials and resources that make our model successful, are both a contribution of this work, and a step towards the *Program Affordances* hypothesis.
- Chapter 5 describes two case studies featuring a pair of example classroom implementations: one in English language and one in Health and Physical Education. These case studies and supporting

documentation provide key implementation details of Arts & Bots within teacher-designed lesson plans and classrooms that existed at the outset of this research. We again see strong support for the *Class Integration* hypothesis, which also plays a role in enumerating the features of Arts & Bots that contribute to the *Program Affordances* hypothesis.

- Chapter 6 discusses the goals and design decisions made during the development of a new type visual programming tool for robotics. We see clearly how designing a tool to meet our "Classroom Compatibility" and "Low Barriers to Entry" goals demonstrates the *Class Integration* hypothesis, and how by enabling "Compelling Behaviors" and "Computational Thinking," Arts & Bots in part enables *Talent Demonstration*. The affordances of the visual programmer are indeed also affordances of the larger Arts & Bots program to be considered with the *Program Affordances* hypothesis.
- Chapter 7 describes the refinement of the Arts & Bots program as a talent identification tool. We cover the reference materials created for teachers, including handouts and a novice-built robot taxonomy, and present our analysis of outcomes seen as a result of these talent identification efforts. In this chapter, we confirm both the *Talent Demonstration* and *Identification Capacity* hypotheses through qualitative and quantitative evaluation of the program. The robot taxonomy of novice-built robots supports teachers in student talent identification, and allows us to analyze and describe the interactions between the system and talent-based learning. Our definitions of Computational Thinking and Engineering Design talent are adaptable to many programs with similar goals, and are a contribution that supports the future training of non-technical teachers.
- Chapter 8 and Chapter 9 illustrate the development of student evaluation tools, and describe student outcomes seen during Arts & Bots projects. Many of these tools are adaptable beyond Arts & Bots, and thus have applications and contributions to the

future evaluation of integrated creative technology programs, and robotics interventions more generally. The outcomes of this evaluation also provide us with a better understanding of how students are impacted by Arts & Bots projects, giving us insight into the effectiveness of Arts & Bots, and supporting the *Class Integration* hypothesis.

In combination, the contributions of this work will be of value both to the development of future educational robotics programs and to our understanding of how teachers can incorporate the identification and support of student talents within their classroom.

Dissemination

The future of Arts & Bots will be focused on the dissemination of our findings, best practices, and recommendations to the many groups could benefit from them. These groups — along with avenues of engagement that we can pursue — are listed below.

1. *Teachers* - We can improve how we engage teachers by using multiple methods of dissemination. First, we can write articles describing Arts & Bots projects and practices for education blogs and education newsletters that are frequently read by practitioners. These would ideally be coauthored with Arts & Bots teachers in order to resonate with readers. Next, we can provide our latest professional development model and materials to PD providers. It will be natural to start with existing CREATE Lab partners, ASSET STEM Education and BirdBrain Technologies. Finally, we will add our latest content — in the form of printable materials, videos, and articles for educators — to the Arts & Bots website at `artsandbots.com`, for easy access.

2. *Administrators* - Our pathways for dissemination to administrators will be similar to those for teachers. In the past, we have successfully spread our ideas and program to administrators through word-of-mouth. Engaged administrators listen to the suggestions of the teachers they work with, which allows us to reach them

when Arts & Bots is championed by teachers. We can also reach administrators directly through professional associations newsletters, and presentations at professional conferences. Locally, we can work to disseminate our models to districts through Pennsylvania Intermediate Units and West Virginia Regional Education Service Agencies.

3. *Pre-Service Teachers* - The CREATE Lab has in place a network of colleges of education and similar organizations — called the CREATE Lab Satellite Network — that make it possible to broadly disseminate programs to the schools and areas served by these organizations. By providing our partners with materials and training on our practices, we will be able to reach countless pre-service educators while they are receiving their education.

4. *Educational Technology Developers* - We will be able to reach educational technology developers and research groups through publication to appropriate educational technology magazines, conferences, and/or journals. The articles that we write for this audience should focus on our design process, and our generalizable design recommendations for future educational technologies.

5. *Education Researchers* - Similarly, we will be able to reach education program developers and research groups through publication to appropriate STEM education conferences and journals. The disruptive nature of Arts & Bots has already drawn much attention to our work at the education conferences we have attended. We have already published and presented on many of the distinct aspects of Arts & Bots. The next logical step is to write a journal paper that brings together the various features of Arts & Bots into a comprehensive overview of the program, our outcomes, and our recommendations for similar programs.

Arts & Bots has already had a direct impact on dozens of teachers and many hundreds of middle school students. Through the dissemination and contributions described in this dissertation, we hope that Arts & Bots will continue to impact and improve the practices of educators and the experiences of students well into the future.

Appendices

Appendix A: Talent Definitions

Talent Definitions

The diverse individual goals supported by Arts & Bots and the Creative Robotics MSP will allow for engagement with student of numerous talents and interests. These include talents in aesthetic and visual communication, computational thinking, engineering design and others. The STEM Talent Identification and Cultivation focus of the MSP project places special interest on the identification of Computational Thinking and Engineering Design talents.

Computational Thinking Talent

Computational thinking (CT) is a set of problem solving skills and techniques which incorporate attitudes and skills that allow real world problems to be solved with methods from computing and computer science (Wing 2006). CT revolves around restructuring and modeling problems so that they can be solved through logical, algorithmic thinking (ISTE & CSTA 2011). CT exercises students' skills in handling complexity, ambiguity, and open-ended problems; persistence in working with difficult problems; and communicating and working with others to achieve a common goal (ISTE & CSTA 2011).

We define ***exceptional computational thinking talent*** as demonstrating above average abilities:

- thinking through different levels of abstraction
- formulating logical data organizations and algorithmic processes
- comparing the efficiency and effectiveness of feasible solutions

PS	**Problem-Solving**

PS.1	**Problem Breakdown**			
Prominent in:	★★ Planning	Building	Programming	Testing
Description	The student can take a large problem and divide it into smaller problems that are each more manageable and, when each is solved, the complex problem becomes easier.			
Example	For example, a student is looking to have a robot perform a complex and long set of actions. Instead of coding it all up into one giant *sequence*, the student thinks of natural, smaller "abilities" for the robot, making a *subsequence* for each of these and testing them individually, then finally making a *sequence* that uses all these smaller *subsequences* together.			

PS.2	**Redefine problems**			
Prominent in:	★★ Planning	Building	Programming	Testing
Description	The student recognizes that a given problem cannot be solved with available resources. She can take that problem and express it in a different way so that available tools (such as the motors and sensors that are available) are more applicable.			
Example	For example, the student is trying to get a robot dog's tail to wag back and forth continuously but cannot get the servo to move slowly enough. Instead of thinking about the problem in terms of a servo moving slowly, continuously, the student can create a program that sets the position of the tail to a series of closely spaced positions, and over ten or twenty such moves, it gives the impression of a slowly wagging tail.			

PS.3	**Strategic decision-making**			
Prominent in:	★ Planning	★★ Building	★★ Programming	Testing
Description	The student compares and weighs possible strategies and solutions, and she is able to make a justifiable decision concerning how to proceed.			
Example	For example, a student wants her robot to blink its eye twenty times, and considers two ways of doing that: making a *sequence* that lists out the blinking *expression* twenty times in a row, or using a counter loop. The student considers which is more work to implement and which is easier to change later. The student chooses to use the loop, because it will be easier to change the number of blinks later on.			

AB	**Abstraction**

AB.1	**Modelling**			
Prominent in:	★ Planning	★ Building	★★ Programming	Testing
Description	The student is able to create a model or simulation to represent a complex system in order to better understand the system. The model represents key elements of the system while ignoring superfluous details.			
Example	For example, the student is trying to create a robotic arm that demonstrates the movement of bones, muscles and tendons. The student first models the elbow joint of the robot using just the servo and two rectangles of cardboard to test the servo motions, prior to creating bone shaped pieces and adding decorative muscles to the final system.			

AB.2	**Pattern Recognition**			
Prominent in:	Planning	★ Building	★★ Programming	Testing
Description	The student is able to consider multiple tasks and recognize the common features that the tasks share.			
Example	For example, a student is programming a complex robot behavior with numerous *subsequences*. The student recognizes that a desired action is similar to an existing *subsequence*. She saves a copy of the existing *subsequence* to use as a template and then modifies the *subsequence* as needed without recreating the shared actions.			

AB.3	**Modularity**			
Prominent in:	Planning	Building	★★ Programming	Testing
Description	A student can recognize which components may be useful for reuse and is able to create solutions that are generalizable for multiple tasks.			
Example	For example, the student is making a robotic mask which expresses different emotions using eye color and mouth position. One solution would be create complete *expressions* for “Jealous”, “Sad”, “Angry” and “Tired” which each contain both eye and mouth settings. A modular solution would be to create separate eye color and mouth position *expressions* which can be combined in different ways to create a wide variety of expressions.			

AT	Algorithmic Thinking

AT.1	**Algorithm Design**
Prominent in:	★ Planning Building ★★ Programming Testing
Description	The student is able to recognize that complex behaviors are, like a cooking recipe, made of simpler steps put together in a specific way. At design time, they are able to identify and name the smaller steps that happen sequentially in order to recreate the overall behavior. Beyond using *expressions* to make *sequences*, an exceptional student will combine *subsequences* to create larger and more elaborate final *sequences*.
Example	For example, while designing a robotic lobster that will talk about ocean currents, the student recognizes that the overall ocean current behavior includes distinct actions for making the speech, snapping the claws, moving eyestalks and arching the lobster's back. He is able to describe the relative timing of such behaviors, the *sequence* of the actions and their relationships to one-another even before having implemented any of them.

AT.2	**Incremental development and evaluation**
Prominent in:	Planning ★★ Building ★★ Programming Testing
Description	The student is able to solve complex challenges by breaking the problem down and implementing simple, manageable parts. One-by-one the student tests and perfects each part and eventually combines them into the full solutions.
Example	For example, a student is creating a robotic theater with a four act play. She designs, tests, and refines each act separately before combining them to create the complete play.

Engineering Design Talent

Engineering design is the process of developing a concrete solution for an ill-defined problem within technical feasibility constraints (Cross 1982, Brown 2008). Engineering design experience develops students' skills in real world problem solving, synthesizing new thoughts and concepts, and communicating mental imagery of designs and concepts through graphical representations (Cross 1982). Our vision of engineering design in K-12 education is a combination of systems engineering concepts, the engineering design process (comparable to the scientific method) and design thinking as popularized by the Stanford d.School and IDEO (Brown 2008).

We define ***exceptional engineering design talent*** as demonstrating above average abilities:

- transforming ambiguous and complex problem spaces into concrete design goals
- developing new concepts and creative solutions for solving design problems
- communicating design concepts using graphical representations and other nonverbal means
- actualizing designs into real-world prototypes, devices or systems

DP	**Defining the Problem**

DP.1	**Defining the Problem**			
Prominent in:	★★ Planning	Building	Programming	Testing
Description	The student can identify criteria for success, constraints and resource limits for a given problem.			
Example	For example, a student is given an open-ended task to make a robot that encourages their peers to recycle cans. The student can recognize the capabilities of materials that they have available to them, they consider the time restraints on the class and determine how they will measure their robot's success at the task.			

ID	**Intentional Design**

ID.1	**Deliberate Planning**			
Prominent in:	★★ Planning	Building	Programming	Testing
Description	The student first comes up with a complete plan and strategy for constructing and programming the robot that they intend to create based on the criteria and constraints and considers how to follow this plan it before beginning construction and programming.			
Example	For example, the student will make sketch designs, flowchart behaviors, make lists and/or take notes—all before actually cutting cardboard, heating glue, et cetera.			

ID.2	**Following a Plan**			
Prominent in:	Planning	★★ Building	★ Programming	Testing
Description	The student has a roadmap for creating the robot and works to follow it despite challenges, rather than changing plans haphazardly while building.			

Example	For example, a student starts with a plan to build a rabbit stand on its rear legs, but then discovers that the rabbit falls over when the servos move. A student who does <u>not</u> stick to the plan may decide, "Well, now I'm building a rabbit that is lying down" without having felt a loyalty to the plan and desire to understand whether she really can get the rabbit to stay standing up. A student who follows the plan will consider the cause of the problem and address it by modifying their robot with a larger base so that the final rabbit matches their planned standing design.

IN	**Innovating**

IN.1	**Generating Multiple Solutions**			
Prominent in:	★★ Planning	Building	Programming	Testing
Description	The student, before constructing or programming the robot or subcomponent, brainstorms two or more possible solutions for each challenge or need instead of just beginning to create the first solution that comes to mind.			
Example	For example, the student might sketch three different ways of attaching a cardboard arm to a servo (e.g., screwing the cardboard to the servo head; gluing the arm to the servo head; or pressing the servo head through a cut in the cardboard and gluing the edges). This talent can also be applied when facing a new problem discovered during the creation of a robot - when an initial design is ineffective, the student considers multiple improvements before proceeding.			

IN.2	**Solution Evaluation**			
Prominent in:	★★ Planning	Building	Programming	Testing
Description	The student, presented with multiple possible solutions, considers carefully the strengths and weaknesses of each potential solution and is able to describe her reason for making a choice. By considering the constraints, criteria and resources for the project, the student can select the solution which meets the success criteria within the given constraints and resources.			
Example	For example, the student considers two ways to have her robot express emotions, she could use servos to control the shape of the robot's mouth or she could use tri-color LEDs to make the eyes a color symbolic of the emotion. She considers that the mouth movements would be too challenging to implement in the remaining project time, while the tri-color eyes will be able to be completed quickly and will still meet the emotion expression criteria, so she chooses to use the tri-color LEDs.			

IN.3	**"Outside the Box"**			
Prominent in:	★★ Planning	★★ Building	★ Programming	Testing
Description	The student demonstrates the ability to come up with possibly risky, very novel solutions to problems. These solutions might incorporate innovative uses of materials, creative mechanisms or generating a solution unlike any examples shown in class.			
Example	For example, the student is constructing a robot that needs to hold a very large sign. The student develops a solution with a helium balloon connected to the sign, allowing the robot to lift the sign with very little force. This is very unconventional thinking and shows out of the box design ability.			

RT	Refining and Testing

RT.1	Systematic Diagnosis			
Prominent in:	Planning	★ Building	★★ Programming	★★ Testing
Description	The student discovers that her robot is not working as expected, either during construction, programming or when completed, and utilizes a <u>methodical</u> process of elimination to determine the source of the problem.			
Example	For example, an exceptional student with a robot that falls over when the arms move, will carefully consider why it is falling and preform a series of tests to determine the issue. She determines that the robot shifts its weight too far forward in certain poses and makes a wedge to put under the robot to shift the center of gravity so that it stops falling over. Students who do not use diagnosis may perform nonsystematic tests (e.g. varying multiple variables at once), try to fix problems through arbitrary modifications, or try to work around the problem by modifying success criteria.			

RT.2	Trade-offs Consideration			
Prominent in:	Planning	★★ Building	★ Programming	Testing
Description	The student is able to recognize when important goals of her robot are at risk of not being accomplished due to resource limitations. The student can prioritize the success criteria and reduce or eliminate features of low priority in order to reach the high priority goals.			
Example	For instance, the student is making a storytelling humanoid robot and she would like to also have it walk across the table. After a few hours of design work, she realizes that the walking goal is much harder to achieve than the primary storytelling goal, and so decides to spend her remaining time making a better stationary storytelling robot since the walking function was disproportionately challenging given the added value. Notice that this thoughtful process and decision is quite different from a student who gives up on the walking goal because they found it difficult without weighing the impact of that decision.			

RT.3	Thorough Testing			
Prominent in:	Planning	★ Building	★ Programming	★★ Testing
Description	The student is careful to test the functionality of each subcomponent of the robot, each component of the program, and the final resulting robot, comparing the test results to their design plan, their expected behavior, and the final criteria for success.			
Example	For instance, a student is building a ball-throwing robot and while building, she tests whether the robot arm can hold the ball at all and makes refinements until it is able to do so. Later, when testing the completed robot, she repeatedly measures how far the ball is thrown with multiple trials to confirm that the robot reliably meets her final criteria for success, e.g. throwing the ball ten feet or more.			

PR	Prototyping

PR.1	Design for Construction			
Prominent in:	★★ Planning	★ Building	Programming	Testing
Description	The student, while designing and constructing their robot, carefully considers how each component will be constructed. By considering the strengths and weaknesses of materials available the student is able to avoid issues that commonly occur in Arts & Bots projects.			
Example	For example, the student is building a robotic draw-bridge model, and recognizes that the cardboard for the bridge bends easily between the ridges of the cardboard. In his initial design he includes a brace underneath the bridge surface with an extra cardboard support perpendicular to the cardboard ridges to correct that material weakness. Also the student will consider the tools available to construct the robot and will plan for how those tools will be used. For example the student building the draw bridge designs the bridge structure such that there are no tight spaces where the glue gun cannot reach and designs doors into the robot so that it is easy to reach the Hummingbird board using a screwdriver in order to wire the robotic components.			

PR.2	Making It Real			
Prominent in:	Planning	★★ Building	Programming	Testing
Description	The student is able to take an idea and create a physical model which accurately reflects the original idea. The model is carefully crafted, constructed with attention to detail, and in the end successfully and elegantly meets the initial design criteria.			
Example	For example, a student envisions the construction of robotic model of a tree. The student approaches this task with great attentional to detail, first selecting a specific tree species and researching the proper leaf shape, bark texture and branching pattern that identifies that species. She then selects the appropriate materials for replicating those features given the resources available and carefully constructs the tree. In the end, she is satisfied that the robotic tree model successfully matched the design idea as she envisioned it.			

CO	Communicating Design

CO.1	Clear Communication of Ideas			
Prominent in:	★★ Planning	★★ Building	★ Programming	★ Testing
Description	The student is able to clearly communicate her design ideas to teammates, teachers and others.			
Example	For example, a student has an idea for an elaborate string-pulley mechanism to move a component on his robot and the student is able to explain the mechanism through sketches, diagrams and sentences to accurately and precisely convey the idea to his teammates.			

Complementary Student Dispositions

These dispositions are complementary to both the Computational Thinking and Engineering Design talents. Each disposition is broadly applicable to diverse disciplines and enhances the student's ability to utilize the talents described in the components above.

Disp.1	Confidence Dealing with Complexity
Description	The student faces complex challenges with confidence and is able to formulate a plan of action for how to proceed.
Ask Yourself	Does a complex challenge paralyze the student, or does he work quickly to break down the problem into bit-size pieces that can each be dealt with in a reasonable time?

Disp.2	Persistence in Working on Difficult Problems
Description	The student demonstrates a tolerance for early failure, and a willingness and excitement to try again.
Ask Yourself	Does the student recognize that it is alright, when making a complex robot or robot behavior, to try several times and run into dead ends, then back out and try again in order to eventually discover a strategy that is successful?

Disp.3	Flexibility
Description	The student is able to adapt to unforeseen complications and discoveries throughout the project.
Ask Yourself	Is the student able to respond to surprises and lessons learned during the building or programming process and use these to beneficially enhance details and goals in ways that are appropriate?

Disp.4	Tolerance for Ambiguity
Description	The student is able to successfully define and follow her own plan when the presented challenge is ambiguous or goals are ill-defined.
Ask Yourself	Is the student able to take a high-level challenge that does not prescribe exactly how the problem should be solved, and prosper? When there is not a single right answer to the problem or easy-to-follow step-by-step directions, can the student define a goal and chart a path to success on her own?

Appendix B: Talent Definitions Summary Handout

Talent Definitions Summary

Computational Thinking Talent

Computational thinking (CT) is a set of problem solving skills and techniques which incorporate attitudes and skills that allow real world problems to be solved with methods from computing and computer science.

We define ***exceptional computational thinking talent*** as demonstrating above average abilities:

- thinking through different levels of abstraction
- formulating logical data organizations and algorithmic processes
- comparing the efficiency and effectiveness of feasible solutions

PS	**Problem-Solving**
Problem Breakdown	Take a large problem and divide it into smaller problems that are each more manageable and, when each is solved, the complex problem becomes easier.
Redefine problems	Recognize that a given problem cannot be solved with available resources. Take the problem and express it in a different way so that available tools (such as the available motors and sensors) are more applicable.
Strategic decision-making	Compare and weigh possible strategies and solutions, and make a justifiable decision concerning how to proceed.

AB	**Abstraction**
Modelling	Create a model or simulation to represent a complex system in order to better understand the system. Represent key elements of the system while ignoring superfluous details.
Pattern Recognition	Consider multiple tasks and recognize the common features that the tasks share.
Modularity	Recognize which components may be useful for reuse and create solutions that are generalizable for multiple tasks.

AT	**Algorithmic Thinking**
Algorithm Design	Identify the sequence of simpler steps that must be created and combined in order to create a more complex behavior. Beyond using *expressions* to make *sequences*, an exceptional student will combine *subsequences* to create larger and more elaborate final *sequences*.
Incremental development and evaluation	Solve complex challenges by breaking the problem down and implementing simple, manageable parts. Test and perfect each part one-by-one and eventually combine them into the full solution.

Engineering Design Talent

Engineering design is the process of developing a concrete solution for an ill-defined problem within technical feasibility constraints.

We define ***exceptional engineering design talent*** as demonstrating above average abilities:

- transforming ambiguous and complex problem spaces into concrete design goals
- developing new concepts and creative solutions for solving design problems
- communicating design concepts using graphical representations and other nonverbal means
- actualizing designs into real-world prototypes, devices or systems

DP	Defining the Problem
Defining the Problem	Identify criteria for success, constraints and resource limits for a given problem.

ID	Intentional Design
Deliberate Planning	First develop a complete plan for constructing and programming the intended robot based on the criteria and constraints. Then consider how to follow this plan before beginning construction and programming.
Following a Plan	Work to follow a design for creating a robot despite challenges, rather than changing plans haphazardly while building.

IN	Innovating
Generating Multiple Solutions	Brainstorm two or more possible solutions for each challenge or need instead of just beginning to create the first solution that comes to mind.
Solution Evaluation	Carefully consider the strengths and weaknesses of multiple potential solutions and describe the reason for making a choice. Use success criteria, and project and resource constraints to select the best solution.
"Outside the Box"	Come up with possibly risky, very novel solutions to problems. These solutions might incorporate innovative uses of materials, creative mechanisms, or a solution unlike any examples shown in class.

RT	Refining and Testing
Systematic Diagnosis	Utilize a methodical process of elimination to determine the source of a problem.
Trade-offs Consideration	Recognize when important goals of the robot are at risk of not being accomplished due to resource limitations. Prioritize the success criteria and reduce or eliminate low priority features in order to reach high priority goals.
Thorough Testing	Carefully test each subcomponent of robot or program, in addition to the whole system, and compare test results to the success criteria.

PR	Prototyping
Design for Construction	During design and construction, carefully consider how each component will be constructed. Consider the strengths and weaknesses of available materials to avoid issues that commonly occur in Arts & Bots projects.
Making It Real	Take an idea and create a physical model which accurately reflects the original idea. The model is carefully crafted, constructed with attention to detail, and successfully and elegantly meets the initial design criteria.

CO	Communicating Design
Clear Communication of Ideas	Clearly communicate design ideas to teammates, teachers, and others.

Complementary Student Dispositions

Confidence Dealing with Complexity	Faces complex challenges with confidence and formulates a plan of action for how to proceed.
Persistence in Working on Difficult Problems	Tolerance for early failure. Willingness and excitement to try again.
Flexibility	Adapts to unforeseen complications and discoveries throughout the project.
Tolerance for Ambiguity	Successfully defines and follow her own plan when the presented challenge is ambiguous or goals are ill-defined.

Appendix C: Talent Inventory Handout

Student Name:____ Date:____________________

PLANNING PHASE

PS.1	Problem Breakdown	
Does the student take a large problem and divide it into smaller, more manageable problems?		☐ Yes
PS.2	Redefine problems	
Does the student redefine a problem such that it may be solved with available tools?		☐ Yes
DP.1	Defining the Problem	
Does the student identify criteria for success, constraints, and resource limits for a given problem?		☐ Yes
ID.1	Deliberate Planning	
Does the student develop a complete plan before he begins construction?		☐ Yes
IN.1	Generating Multiple Solutions	
Does the student generate multiple design solutions before implementation?		☐ Yes
IN.2	Solution Evaluation	
Does the student carefully consider the strengths and weaknesses of potential solutions against project constraints and success criteria before selecting a solution?		☐ Yes
PR.1	Design for Construction	
Does the student carefully plan how each component will be constructed taking strengths and weaknesses of materials into consideration?		☐ Yes

Notes:

Student Name:____ Date:___________________

BUILDING PHASE

IN.3	"Outside the Box"	
Does the student generate risky, innovative, or novel solutions to problems?		☐ Yes
CO.1	Clear Communication of Ideas	
Does the student clearly communicate her design ideas to teammates, teachers and others?		☐ Yes
ID.2	Following a Plan	
Does the student to follow it despite challenges, rather than changing plans haphazardly while building.		☐ Yes
RT.2	Trade-offs Consideration	
Does the student prioritize goals and reduce features of lower importance in order to achieve more critical goals?		☐ Yes
PR.2	Making It Real	
Does the student take an idea and create a carefully crafted and elegantly executed physical model which accurately reflects the original idea?		☐ Yes

Notes:

Student Name:____ Date:____________________

PROGRAMMING PHASE

PS.3	Strategic decision-making	
Does the student compare and weigh possible solutions and make justifiable choices?		☐ Yes
AT.2	Incremental development and evaluation	
Does the student solve complex challenges by breaking the problem into smaller manageable parts, solving each problem part and combining those into the full solutions?		☐ Yes
AB.1	Modelling	
Does the student create models or simulations which represent complex systems by representing key elements of the systems being modelled while ignoring superfluous detail?		☐ Yes
AB.2	Pattern Recognition	
Does the student consider multiple tasks and see the common features that the tasks share?		☐ Yes
AB.3	Modularity	
Does the student recognize which components are reusable for solving multiple problems and create solutions generalized to permit that reuse?		☐ Yes
AT.1	Algorithm Design	
Does the student identify the steps necessary to achieve a complex behavior? Does the student create those steps and combine them to create elaborate behaviors?		☐ Yes

Notes:

Student Name:____ Date:__________________

TESTING

RT.1	Systematic Diagnosis	
Does the student utilize a methodical process of elimination to determine the source of a problem?		☐ Yes
RT.3	Thorough Testing	
Does the student carefully test the functionality of each component of the robot and program against the goal?		☐ Yes

Notes:

SHARED DISPOSITIONS

Disp.1	Confidence Dealing with Complexity	
Does the student work to break down the problem into bit-size pieces that can each be dealt with in a reasonable time without being paralyzed by complexity?		☐ Yes
Disp.2	Persistence in Working on Difficult Problems	
Does the student demonstrate persistence when faced with difficult problems?		☐ Yes
Disp.3	Flexibility	
Does the student respond well to surprises and lessons learned during the project and use these to beneficially enhance their process in appropriate ways?		☐ Yes
Disp.4	Tolerance for Ambiguity	
Does the student, when faced with an ambiguous problem, define a goal and chart a path to success on her own?		☐ Yes

Notes:

Appendix D: Student Pre-Surveys

Arts & Bots MSP Student Pre-Survey

This survey is part of the Arts & Bots research study. The purpose of this research is to improve student experiences in science, technology, math, and engineering education. The survey is expected to take less than 40 minutes.

This is not a test. Your answers will not be graded. But it is important to answer the questions yourself, without asking anyone else for help.

Please answer each question carefully and to the best of your ability. Your answers will help us to improve education for future students.

1. Please write your *first and last* name here. Today's Date

2. Who is your teacher for this class?

Allegheny Valley School District:
[redacted]

Burch Middle School :
[redacted]

Gilbert Middle School:
[redacted]

Kermit PK-8:
[redacted]

Lenore PK-8:
[redacted]

Matewan PK-8:
[redacted]

Williamson PK-8:
[redacted]

Other – Please write here:

3. What is the name of this class?

- ◯ Art
- ◯ Health
- ◯ Reading
- ◯ Science
- ◯ Social Studies
- ◯ Tech Ed

Other – Please write here:

4. What is the skill level of this class?
   - ○ AP level
   - ○ Honors level
   - ○ College Prep level
   - ○ General level

5. What grade are you in?

○ 5	○ 9
○ 6	○ 10
○ 7	○ 11
○ 8	○ 12

6. How old are you?

○ 10	○ 13	○ 16
○ 11	○ 14	○ 17
○ 12	○ 15	○ 18

7. Are you excited to do this project? Why or why not?

8. What do you expect to learn during this Arts & Bots project?

9. New ideas and projects sometimes distract me from previous ones.
- ○ Very much like me
- ○ Mostly like me
- ○ Somewhat like me
- ○ Not much like me
- ○ Not like me at all

10. Setbacks (delays and obstacles) don't discourage me. I bounce back from disappointments faster than most people.
- ○ Very much like me
- ○ Mostly like me
- ○ Somewhat like me
- ○ Not much like me
- ○ Not like me at all

11. I have been obsessed with a certain idea or project for a short time but later lost interest.
- ○ Very much like me
- ○ Mostly like me
- ○ Somewhat like me
- ○ Not much like me
- ○ Not like me at all

12. I am a hard worker.
    - ○ Very much like me
    - ○ Mostly like me
    - ○ Somewhat like me
    - ○ Not much like me
    - ○ Not like me at all

13. I often set a goal but later choose to pursue (follow) a different one.
    - ○ Very much like me
    - ○ Mostly like me
    - ○ Somewhat like me
    - ○ Not much like me
    - ○ Not like me at all

14. I have difficulty maintaining (keeping) my focus on projects that take more than a few months to complete.
    - ○ Very much like me
    - ○ Mostly like me
    - ○ Somewhat like me
    - ○ Not much like me
    - ○ Not like me at all

15. I finish whatever I begin.
    - ○ Very much like me
    - ○ Mostly like me
    - ○ Somewhat like me
    - ○ Not much like me
    - ○ Not like me at all

16. I am diligent (hard working and careful).
    - ○ Very much like me
    - ○ Mostly like me
    - ○ Somewhat like me
    - ○ Not much like me
    - ○ Not like me at all

17. Please select the answer that shows how you feel right now about the statement. There are no right or wrong answers, just be honest.

	NO!	no	Neither yes or no	yes	YES!
I feel good when I learn about technology.	○	○	○	○	○
I am not good at making robots.	○	○	○	○	○
It's important to me to know more about technology than most people.	○	○	○	○	○
I could learn to build a robot.	○	○	○	○	○
I feel uncomfortable when someone talks to me about technology.	○	○	○	○	○
Whenever I use something that is computerized, I am afraid I will break it.	○	○	○	○	○
I like designing new things.	○	○	○	○	○
I look for as much information as I can about robots.	○	○	○	○	○
If I started a robotics project, I think I could do a really good job.	○	○	○	○	○
I can write a computer program.	○	○	○	○	○
I would like to learn more about robotics.	○	○	○	○	○
I can communicate my ideas to my team.	○	○	○	○	○
I am a technical type person.	○	○	○	○	○
It makes me nervous to even think about using computers.	○	○	○	○	○
I am good at thinking logically.	○	○	○	○	○
I get excited about discussing technology.	○	○	○	○	○

18. Please select the answer that shows how you feel right now about the statement. There are no right or wrong answers, just be honest.

	NO!	no	Neither yes or no	yes	YES!
I like to learn new facts about robots.	○	○	○	○	○
I am a good team member.	○	○	○	○	○
I am the kind of person who works well with technology.	○	○	○	○	○
I ask a lot of questions about robots if I don’t understand them.	○	○	○	○	○
I come up with solutions that other people don't think of.	○	○	○	○	○
Robots are boring to me.	○	○	○	○	○
I can program a robot.	○	○	○	○	○
I feel confident about my ability to make robots.	○	○	○	○	○
I have a good feeling about computers.	○	○	○	○	○
Other people think of me as a technical type person.	○	○	○	○	○
I like solving complex problems.	○	○	○	○	○
Technology is interesting to me.	○	○	○	○	○
Learning about robots is important to me.	○	○	○	○	○
I like to watch TV shows and/or read about robots.	○	○	○	○	○
I am good at making robots.	○	○	○	○	○
Everywhere I go, I am out looking for new things about robots.	○	○	○	○	○
I am the type of person who could become a roboticist.	○	○	○	○	○

19. Please select the answer that shows how you feel right now about the statement. There are no right or wrong answers, just be honest.

	NO!	no	Neither yes or no	yes	YES!
I like to do robotics activities.	○	○	○	○	○
I am interested in discovering things about robots.	○	○	○	○	○
I like working on teams.	○	○	○	○	○
I like to prove that I know more about technology than my friends.	○	○	○	○	○
When I don't know something about computers, I try and find an answer.	○	○	○	○	○
I could learn to write a computer program.	○	○	○	○	○
I want to learn everything about technology, even if it's complicated.	○	○	○	○	○
It is cool to learn new things about robots.	○	○	○	○	○
I am often trying to find out more about computers.	○	○	○	○	○
I can make a robot.	○	○	○	○	○
I know I can learn a lot about robots.	○	○	○	○	○
I enjoy exploring new ideas about robotics.	○	○	○	○	○
I am good at designing things.	○	○	○	○	○
I try to do activities related to technology.	○	○	○	○	○
Robotics is interesting to me.	○	○	○	○	○
I solve problems logically.	○	○	○	○	○
I am curious about how robots work.	○	○	○	○	○

Choose one circle between each adjective pair to indicate how you feel about the object. Usually it is best to respond with your first impression, without giving a question much thought.

To me, ENGINEERING (is):

	1	2	3	4	5	6	7	
15. appealing	○	○	○	○	○	○	○	unappealing
16. fascinating	○	○	○	○	○	○	○	mundane
17. means nothing	○	○	○	○	○	○	○	means a lot
18. exciting	○	○	○	○	○	○	○	unexciting
19. boring	○	○	○	○	○	○	○	interesting

Choose one circle between each adjective pair to indicate how you feel about the object. Usually it is best to respond with your first impression, without giving a question much thought.

To me, TECHNOLOGY (is):

20.	1	2	3	4	5	6	7	
appealing	○	○	○	○	○	○	○	unappealing

21.	1	2	3	4	5	6	7	
means nothing	○	○	○	○	○	○	○	means a lot

22.	1	2	3	4	5	6	7	
boring	○	○	○	○	○	○	○	interesting

23.	1	2	3	4	5	6	7	
exciting	○	○	○	○	○	○	○	unexciting

24.	1	2	3	4	5	6	7	
fascinating	○	○	○	○	○	○	○	mundane

Choose one circle between each adjective pair to indicate how you feel about the object. Usually it is best to respond with your first impression, without giving a question much thought.

To me, a CAREER in science, technology, engineering, or mathematics (is):

	1	2	3	4	5	6	7	
25. means nothing	○	○	○	○	○	○	○	means a lot
26. boring	○	○	○	○	○	○	○	interesting
27. exciting	○	○	○	○	○	○	○	unexciting
28. fascinating	○	○	○	○	○	○	○	mundane
29. appealing	○	○	○	○	○	○	○	unappealing

30. Are these things that an engineer would do for his or her job?

Develop better bubble gum	Yes ○	No ○
Install cable television	Yes ○	No ○
Nail beams together for new houses	Yes ○	No ○
Come up with ways to keep soup hot for a picnic	Yes ○	No ○
Develop smaller cell phones	Yes ○	No ○
Drive motor boats	Yes ○	No ○
Design tools for surgery	Yes ○	No ○
Design ways to clean polluted air	Yes ○	No ○
Drive garbage trucks	Yes ○	No ○
Figure out ways to explore the ocean	Yes ○	No ○
Install wiring	Yes ○	No ○
Put shelves together in a store	Yes ○	No ○
Pour cement for new roads	Yes ○	No ○
Figure out how tall you can safely build towers	Yes ○	No ○

Choose the best description for each component.

31. Distance sensor
    - ○ Detects when there is or is not motion.
    - ○ Senses angular position.
    - ○ Produces a small rapid back and forth motion.
    - ○ Detects the amount of space between itself and an object in front of it.

32. LED
    - ○ Creates light.
    - ○ Detects heat.
    - ○ Changes electrical signals into sound.
    - ○ Detects levels of brightness and darkness.

33. Light sensor
    - ○ Heats or cools objects.
    - ○ Creates light.
    - ○ Detects levels of brightness and darkness.
    - ○ Starts or stops the flow of electricity through a circuit when it is pressed or moved.

34. Microcontroller board, such as the Hummingbird board
    - ○ Starts or stops the flow of electricity through a circuit when it is pressed or moved.
    - ○ Is a set of instructions that tell a computer what to do.
    - ○ Produces a small rapid back and forth motion.
    - ○ Is a small programmable computer.

35. Motor
    - ○ Can be set to a precise angular position.
    - ○ Detects when there is or is not motion.
    - ○ Senses angular position.
    - ○ Produces rotating motion.

36. Potentiometer
    - ○ Is a small programmable computer.
    - ○ Produces rotating motion.
    - ○ Senses angular position.
    - ○ Changes electrical signals into sound.

37. Servo
    - ○ Can be set to a precise angular position.
    - ○ Creates light.
    - ○ Changes electrical signals into sound.
    - ○ Senses angular position.

38. Temperature sensor
   - ○ Detects pressure or force.
   - ○ Detects heat.
   - ○ Heats or cools objects.
   - ○ Starts or stops the flow of electricity through a circuit when it is pressed or moved.

39. Vibration motor
   - ○ Produces a small rapid back and forth motion.
   - ○ Detects pressure or force.
   - ○ Can be set to a precise angular position.
   - ○ Starts or stops the flow of electricity through a circuit when it is pressed or moved.

40. 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.

	Input	Output	Processing
A beep from your computer	○	○	○
The glowing of an LED on a traffic light	○	○	○
Pressing a button on your phone	○	○	○
The detection of your hand by a distance sensor in hand dryer	○	○	○
A printout from your printer	○	○	○
Thinking about which soda you want from a machine	○	○	○
The cooling of a temperature sensor in a refrigerator	○	○	○
A picture on your computer monitor	○	○	○
Talking into a cell phone	○	○	○
A microcontroller board in a mp3 player determining what song to play next on a play list	○	○	○
The spinning of a motor in a robot	○	○	○
Covering a light sensor in a night light	○	○	○
Twisting a potentiometer in a light dimmer knob	○	○	○

	Input	Output	Processing
A calculator adding a sum	○	○	○
The movement of a remote controlled car	○	○	○
The ringing of your alarm clock	○	○	○
Your digestion of breakfast	○	○	○
The repositioning of a servo on a remote control airplane	○	○	○
The shaking of a vibration motor in a cell phone	○	○	○

41. Have you ever done an Arts & Bots project before?
    - ○ No
    - ○ Yes – Please write how many times in the box **---->**

Number of prior Arts & Bots projects:

42. What experiences have you had working with circuits or robots?

43. What experiences have you had programming computers or robots?

44. What is your gender?
- ○ Male
- ○ Female

45. What is your ethnicity?
- ○ Hispanic or Latino
- ○ Not Hispanic or Latino

46. What is your race (select one or more)?
- ○ American Indian or Alaska Native
- ○ Asian
- ○ Black or African American
- ○ Native Hawaiian or Other Pacific Islander
- ○ White

You have completed this Arts & Bots Pre-Survey. This survey was part of the Arts & Bots research study. Please check that you answered all of the questions and return this survey to your teacher or an Arts & Bots researcher.

Thank You!

Appendix E: Student Post-Surveys

Arts & Bots MSP Student Post-Survey

This survey is part of the Arts & Bots research study. The purpose of this research is to improve student experiences in science, technology, math, and engineering education. The survey is expected to take less than 40 minutes.

This is not a test. Your answers will not be graded. But it is important to answer the questions yourself, without asking anyone else for help.

Please answer each question carefully and to the best of your ability. Your answers will help us to improve education for future students.

1. Please write your *first and last* name here. Today's Date

2. Who is your teacher for this class?

Allegheny Valley School District:
[redacted]

Burch Middle School :
[redacted]

Gilbert Middle School:
[redacted]

Kermit PK-8:
[redacted]

Lenore PK-8:
[redacted]

Matewan PK-8:
[redacted]

Williamson PK-8:
[redacted]

Other – Please write here:

3. What is the name of this class?

- ◯ Art
- ◯ Health
- ◯ Reading
- ◯ Science
- ◯ Social Studies
- ◯ Tech Ed

Other – Please write here:

4. What is the skill level of this class?
   - ◯ AP level
   - ◯ Honors level
   - ◯ College level
   - ◯ General level

5. What grade are you in?
   - ◯ 5
   - ◯ 6
   - ◯ 7
   - ◯ 8
   - ◯ 9
   - ◯ 10
   - ◯ 11
   - ◯ 12

6. How did this experience change how you think about technology?

7. Did you enjoy doing this project? Why or why not?

8. Should other students have this experience? Why or why not?

9. Do you have any suggestions for improvements?

10. What was the best thing that you learned during the project?

11. How did your Arts & Bots experience compare with your expectations?

Coming up with an idea and designing a robot is…

- ◯ much easier than I thought.
- ◯ easier than I thought.
- ◯ about as I expected.
- ◯ harder than I thought.
- ◯ much harder than I thought.

Building a robot is…

- ◯ much easier than I thought.
- ◯ easier than I thought.
- ◯ about as I expected.
- ◯ harder than I thought.
- ◯ much harder than I thought.

Programming a robot is…

- ◯ much easier than I thought.
- ◯ easier than I thought.
- ◯ about as I expected.
- ◯ harder than I thought.
- ◯ much harder than I thought.

Working on a team is…

- ◯ much easier than I thought.
- ◯ easier than I thought.
- ◯ about as I expected.
- ◯ harder than I thought.
- ◯ much harder than I thought.

12. Please select the answer that shows how you feel right now about the statement. There are no right or wrong answers, just be honest.

	NO!	no	Neither yes or no	yes	YES!
I feel good when I learn about technology.	○	○	○	○	○
I am not good at making robots.	○	○	○	○	○
It's important to me to know more about technology than most people.	○	○	○	○	○
I could learn to build a robot.	○	○	○	○	○
I feel uncomfortable when someone talks to me about technology.	○	○	○	○	○
Whenever I use something that is computerized, I am afraid I will break it.	○	○	○	○	○
I like designing new things.	○	○	○	○	○
I look for as much information as I can about robots.	○	○	○	○	○
If I started a robotics project, I think I could do a really good job.	○	○	○	○	○
I can write a computer program.	○	○	○	○	○
I would like to learn more about robotics.	○	○	○	○	○
I can communicate my ideas to my team.	○	○	○	○	○
I am a technical type person.	○	○	○	○	○
It makes me nervous to even think about using computers.	○	○	○	○	○
I am good at thinking logically.	○	○	○	○	○
I get excited about discussing technology.	○	○	○	○	○

13. Please select the answer that shows how you feel right now about the statement. There are no right or wrong answers, just be honest.

	NO!	no	Neither yes or no	yes	YES!
I like to learn new facts about robots.	○	○	○	○	○
I am a good team member.	○	○	○	○	○
I am the kind of person who works well with technology.	○	○	○	○	○
I ask a lot of questions about robots if I don't understand them.	○	○	○	○	○
I come up with solutions that other people don't think of.	○	○	○	○	○
Robots are boring to me.	○	○	○	○	○
I can program a robot.	○	○	○	○	○
I feel confident about my ability to make robots.	○	○	○	○	○
I have a good feeling about computers.	○	○	○	○	○
Other people think of me as a technical type person.	○	○	○	○	○
I like solving complex problems.	○	○	○	○	○
Technology is interesting to me.	○	○	○	○	○
Learning about robots is important to me.	○	○	○	○	○
I like to watch TV shows and/or read about robots.	○	○	○	○	○
I am good at making robots.	○	○	○	○	○
Everywhere I go, I am out looking for new things about robots.	○	○	○	○	○
I am the type of person who could become a roboticist.	○	○	○	○	○

14. Please select the answer that shows how you feel right now about the statement. There are no right or wrong answers, just be honest.

	NO!	no	Neither yes or no	yes	YES!
I like to do robotics activities.	○	○	○	○	○
I am interested in discovering things about robots.	○	○	○	○	○
I like working on teams.	○	○	○	○	○
I like to prove that I know more about technology than my friends.	○	○	○	○	○
When I don't know something about computers, I try and find an answer.	○	○	○	○	○
I could learn to write a computer program.	○	○	○	○	○
I want to learn everything about technology, even if it's complicated.	○	○	○	○	○
It is cool to learn new things about robots.	○	○	○	○	○
I am often trying to find out more about computers.	○	○	○	○	○
I can make a robot.	○	○	○	○	○
I know I can learn a lot about robots.	○	○	○	○	○
I enjoy exploring new ideas about robotics.	○	○	○	○	○
I am good at designing things.	○	○	○	○	○
I try to do activities related to technology.	○	○	○	○	○
Robotics is interesting to me.	○	○	○	○	○
I solve problems logically.	○	○	○	○	○
I am curious about how robots work.	○	○	○	○	○

Choose one circle between each adjective pair to indicate how you feel about the object. Usually it is best to respond with your first impression, without giving a question much thought.

To me, ENGINEERING (is):

	1	2	3	4	5	6	7	
13. appealing	○	○	○	○	○	○	○	unappealing
14. fascinating	○	○	○	○	○	○	○	mundane
15. means nothing	○	○	○	○	○	○	○	means a lot
16. exciting	○	○	○	○	○	○	○	unexciting
17. boring	○	○	○	○	○	○	○	interesting

Choose one circle between each adjective pair to indicate how you feel about the object. Usually it is best to respond with your first impression, without giving a question much thought.

To me, TECHNOLOGY (is):

18.	1	2	3	4	5	6	7	
appealing	○	○	○	○	○	○	○	unappealing

19.	1	2	3	4	5	6	7	
means nothing	○	○	○	○	○	○	○	means a lot

20.	1	2	3	4	5	6	7	
boring	○	○	○	○	○	○	○	interesting

21.	1	2	3	4	5	6	7	
exciting	○	○	○	○	○	○	○	unexciting

22.	1	2	3	4	5	6	7	
fascinating	○	○	○	○	○	○	○	mundane

Choose one circle between each adjective pair to indicate how you feel about the object. Usually it is best to respond with your first impression, without giving a question much thought.

To me, a CAREER in science, technology, engineering, or mathematics (is):

23.	1	2	3	4	5	6	7	
means nothing	○	○	○	○	○	○	○	means a lot

24.	1	2	3	4	5	6	7	
boring	○	○	○	○	○	○	○	interesting

25.	1	2	3	4	5	6	7	
exciting	○	○	○	○	○	○	○	unexciting

26.	1	2	3	4	5	6	7	
fascinating	○	○	○	○	○	○	○	mundane

27.	1	2	3	4	5	6	7	
appealing	○	○	○	○	○	○	○	unappealing

28. Are these things that an engineer would do for his or her job?

Develop better bubble gum	Yes ○	No ○
Install cable television	Yes ○	No ○
Nail beams together for new houses	Yes ○	No ○
Come up with ways to keep soup hot for a picnic	Yes ○	No ○
Develop smaller cell phones	Yes ○	No ○
Drive motor boats	Yes ○	No ○
Design tools for surgery	Yes ○	No ○
Design ways to clean polluted air	Yes ○	No ○
Drive garbage trucks	Yes ○	No ○
Figure out ways to explore the ocean	Yes ○	No ○
Install wiring	Yes ○	No ○
Put shelves together in a store	Yes ○	No ○
Pour cement for new roads	Yes ○	No ○
Figure out how tall you can safely build towers	Yes ○	No ○

Choose the best description for each component.

29. Distance sensor
- ○ Detects when there is or is not motion.
- ○ Senses angular position.
- ○ Produces a small rapid back and forth motion.
- ○ Detects the amount of space between itself and an object in front of it.

30. LED
- ○ Creates light.
- ○ Detects heat.
- ○ Changes electrical signals into sound.
- ○ Detects levels of brightness and darkness.

31. Light sensor
- ○ Heats or cools objects.
- ○ Creates light.
- ○ Detects levels of brightness and darkness.
- ○ Starts or stops the flow of electricity through a circuit when it is pressed or moved.

32. Microcontroller board, such as the Hummingbird board
- ○ Starts or stops the flow of electricity through a circuit when it is pressed or moved.
- ○ Is a set of instructions that tell a computer what to do.
- ○ Produces a small rapid back and forth motion.
- ○ Is a small programmable computer.

33. Motor
- ○ Can be set to a precise angular position.
- ○ Detects when there is or is not motion.
- ○ Senses angular position.
- ○ Produces rotating motion.

34. Potentiometer
- ○ Is a small programmable computer.
- ○ Produces rotating motion.
- ○ Senses angular position.
- ○ Changes electrical signals into sound.

35. Servo
- ○ Can be set to a precise angular position.
- ○ Creates light.
- ○ Changes electrical signals into sound.
- ○ Senses angular position.

36. Temperature sensor
   - ○ Detects pressure or force.
   - ○ Detects heat.
   - ○ Heats or cools objects.
   - ○ Starts or stops the flow of electricity through a circuit when it is pressed or moved.

37. Vibration motor
   - ○ Produces a small rapid back and forth motion.
   - ○ Detects pressure or force.
   - ○ Can be set to a precise angular position.
   - ○ Starts or stops the flow of electricity through a circuit when it is pressed or moved.

38. 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.

	Input	Output	Processing
A beep from your computer	○	○	○
The glowing of an LED on a traffic light	○	○	○
Pressing a button on your phone	○	○	○
The detection of your hand by a distance sensor in hand dryer	○	○	○
A printout from your printer	○	○	○
Thinking about which soda you want from a machine	○	○	○
The cooling of a temperature sensor in a refrigerator	○	○	○
A picture on your computer monitor	○	○	○
Talking into a cell phone	○	○	○
A microcontroller board in a mp3 player determining what song to play next on a play list	○	○	○
The spinning of a motor in a robot	○	○	○
Covering a light sensor in a night light	○	○	○

	Input	Output	Processing
Twisting a potentiometer in a light dimmer knob	○	○	○
A calculator adding a sum	○	○	○
The movement of a remote controlled car	○	○	○
The ringing of your alarm clock	○	○	○
Your digestion of breakfast	○	○	○
The repositioning of a servo on a remote control airplane	○	○	○
The shaking of a vibration motor in a cell phone	○	○	○

39. How much time did you spend on each of these?

	None	A little	A fair amount	A moderate amount	A large amount	An extensive amount
The class topic (poem analysis, researching science concepts, etc.)	○	○	○	○	○	○
Designing and planning (brainstorming, sketching, storyboarding, etc.)	○	○	○	○	○	○
Building or working with Hummingbird, motors, LEDs, or sensors	○	○	○	○	○	○
Art or decoration	○	○	○	○	○	○
Programming	○	○	○	○	○	○
Presenting or demonstrating your project	○	○	○	○	○	○
Other	○	○	○	○	○	○

If you spent time on "Other" areas, please describe:

40. Briefly describe your robot. Which sensors did you use? Which other robot components did you use?

You have completed this Arts & Bots Post-Survey. This survey was part of the Arts & Bots research study. Please check that you answered all of the questions and return this survey to your teacher or an Arts & Bots researcher. **Thank You!**

Appendix F: Student Exit Ticket

First Name: ______________________ Last Name: ________________________

Arts & Bots Exit Ticket

Complete these questions at the end of each work session. Answer for yourself (not your team).

Be honest – there are no right or wrong answers!

Date:___/____/____

Today, I worked on: ☐ I was absent this day ☐ Class Subject ☐ Designing & Planning ☐ Building or Working with Robot Parts ☐ Art or decoration ☐ Programming ☐ Final presentation ☐ Other

Please explain "Other":

How challenging did you find this session's activities? challenge too low ◯ ◯ ◯ challenge just right ◯ ◯ challenge too high

Date:___/____/____

Today, I worked on: ☐ I was absent this day ☐ Class Subject ☐ Designing & Planning ☐ Building or Working with Robot Parts ☐ Art or decoration ☐ Programming ☐ Final presentation ☐ Other

Please explain "Other":

How challenging did you find this session's activities? challenge too low ◯ ◯ ◯ challenge just right ◯ ◯ challenge too high

Date:___/____/____

Today, I worked on: ☐ I was absent this day ☐ Class Subject ☐ Designing & Planning ☐ Building or Working with Robot Parts ☐ Art or decoration ☐ Programming ☐ Final presentation ☐ Other

Please explain "Other":

How challenging did you find this session's activities? challenge too low ◯ ◯ ◯ challenge just right ◯ ◯ challenge too high

Date:___/____/____

Today, I worked on: ☐ I was absent this day ☐ Class Subject ☐ Designing & Planning ☐ Building or Working with Robot Parts ☐ Art or decoration ☐ Programming ☐ Final presentation ☐ Other

Please explain "Other":

How challenging did you find this session's activities? challenge too low ◯ ◯ ◯ challenge just right ◯ ◯ challenge too high

Make more copies as needed

Date:___ /____ /____

Today, I worked on:

I was absent this day	Class Subject	Designing & Planning	Building or Working with Robot Parts	Art or decoration	Programming	Final presentation	Other
☐	☐	☐	☐	☐	☐	☐	☐

Please explain "Other":

How challenging did you find this session's activities?

challenge too low		challenge just right		challenge too high
○	○	○	○	○

Date:___ /____ /____

Today, I worked on:

I was absent this day	Class Subject	Designing & Planning	Building or Working with Robot Parts	Art or decoration	Programming	Final presentation	Other
☐	☐	☐	☐	☐	☐	☐	☐

Please explain "Other":

How challenging did you find this session's activities?

challenge too low		challenge just right		challenge too high
○	○	○	○	○

Date:___ /____ /____

Today, I worked on:

I was absent this day	Class Subject	Designing & Planning	Building or Working with Robot Parts	Art or decoration	Programming	Final presentation	Other
☐	☐	☐	☐	☐	☐	☐	☐

Please explain "Other":

How challenging did you find this session's activities?

challenge too low		challenge just right		challenge too high
○	○	○	○	○

Date:___ /____ /____

Today, I worked on:

I was absent this day	Class Subject	Designing & Planning	Building or Working with Robot Parts	Art or decoration	Programming	Final presentation	Other
☐	☐	☐	☐	☐	☐	☐	☐

Please explain "Other":

How challenging did you find this session's activities?

challenge too low		challenge just right		challenge too high
○	○	○	○	○

Date:___ /____ /____

Today, I worked on:

I was absent this day	Class Subject	Designing & Planning	Building or Working with Robot Parts	Art or decoration	Programming	Final presentation	Other
☐	☐	☐	☐	☐	☐	☐	☐

Please explain "Other":

How challenging did you find this session's activities?

challenge too low		challenge just right		challenge too high
○	○	○	○	○

Appendix G: Short Answer Coding Instructions

Student Attitudes Coding Scheme – MSP Year 3 - Clustered

(Version with updates made when trying the code on 24Mar16.)

Questions: (This does not cover all open ended questions.)

- Pre:
  - Are you excited to do this project? Why or why not?
  - What do you expect to learn during this Arts & Bots project?
    - Note: We didn't have this question during Pioneers, but it might work with this coding scheme.
- Post:
  - How did this experience change how you think about technology?
  - Did you enjoy doing this project? Why or why not?
  - Should other students have this experience? Why or why not?
  - Do you have any suggestions for improvements?
  - What was the best thing that you learned during the project?

Some responses may be coded into multiple categories, but the same piece of text should not be double coded.

"How did this experience change…": Yes and No counted as non-answer because they did not answer the question that was being asked. They may be answering "did this experience change…" but we can't judge if the answer/change is a positive or negative valence.

An answer of just "I don't know" is coded as a non-response instead of a neutral response. If they said "I don't know" followed by positive and negative sides to the answer, it would be coded as Mixed (see 3 below). (Except for the question "Do you have any suggestions…" See below.)

0	**Non-Answer** **0 Non-answer** • [blank] • "?". "lol" • "I don't know" with nothing else • "I don't care" • Other nonsensical responses • Answer a "How?" or "What?" question with just the word "yes" or "no"

	Do you have any suggestions for improvements?
2 Do you have any suggestions…?	**No** **21 [blank] or "I don't know"** **23 No** • "No" with nothing else stated. **24 No, with more explanation** • "no it was fun and perfect the way it was"
1 Do you have any suggestions…?	**Yes** **100 Yes [Vague negative]** • "Yes" – with no reasons given **101 Don't do this project [Dislike, not specified]** **106 Change the class topic [Don't like topic]** • Change the focus to something other than the subject area **13 More personal choice within topic** • "Let us choose our poems" • "More poems to choose from" • "Model a different part of the body" **14 Make it available outside of school** • "Make the kits cheaper for people outside of school." • [positive] **Other codes from Category (1) below can also be used.**
3 Do you have any suggestions…?	**3 Other** • Advise to other students that really doesn't fit another category • "Worry about expressions and sequences first, then worry about the artwork."

Negative		Positive
100 Vague negative • Negative responses that cannot be interpreted for meaning given the answer alone • "No" with nothing else stated (for questions: Are you excited? Did you enjoy? Should others?)	**300 Vague – Undetermined** • Vague • Can't determine if it is positive or negative • "A lot" with nothing else (for "How did this experience change")	**200 Vague positive** • Positive responses that cannot be interpreted for meaning given the answer alone • "Yes" with nothing else stated (for questions: Are you excited? Did you enjoy? Should others?) • "it helped" • If it is vague, and also another code, just assign the other code. • For *Should others…?* "They get to work with technology." • For *Did you enjoy…?* If they just say "yes" or "I enjoyed it" it is vague positive. If they say "yes" or "I enjoyed it" with more explanation, just assign the code for the other explanation.

B1 - Disliking	B2 - Liking
101 Not fun or Dislike (not specific) • They dislike it or it is not fun. • "I didn't like it [experience]" • "I don't like it." • "I didn't like it" • "They won't like it" • "It was not fun"	**201 Fun and Enjoyment (general or technology)** • *Are you excited to do this project? (Said they thought it would be fun or enjoyable.)* • *Did you enjoy doing this project? (Said they enjoyed it because it was fun or they enjoyed working with technology.)* • *Should other students have this experience? (Said yes because it was fun or enjoyable. Said yes because the project or working with technology was fun and enjoyable.)* • *Do you have any suggestions for improvements? (Said no, noting that it was fun.)* • *What was the best thing that you learned during the project? (Said that the project or technology is fun and enjoyable.)* • *How did this experience change how you think about technology? (Said it increased enjoyment or liking of technology. No change plus fun gets 3 and Fun code.)* • Fun, enjoyment, liking (with or without mentioning technology). • They anticipate it will be fun but do not specify which aspect they find appealing. Or they specifically mention enjoyment, liking, or excitement for robots, robotics, technology, computers, electronics, programming, robots, or robotics.

	• "I like this sort of thing" • "I liked it" • "It is fun", "It was fun", "I think it will be fun", "I enjoy technology" • "I learned technology is fun" (This is not about learning technology or learning something vague. This is saying technology is fun.) • "It sounds fun" • "I enjoyed it", "It was enjoyable" • "It is a good experience" • "It was fun working with technology" • "I like robots" • "Programming and robotics is fun", "Robots are fun" • "Technology is *cool*." • "I like programming" • "It was fun working with technology", "I liked working with technology" • *Note: This is different from I want to learn about robots (see Learning category below).* • *Did you enjoy…?* "I got to work with technology" • *Did you enjoy…?* "I enjoyed it but (something negative)" *gets a 200 for the positive half and the specific code for the negative half.* **205 Special case:** "Now I like it even more!" • **Give 205 code and 201.** This is not counted in coding reliability. Is to be used just to identify people for potential case study. • "I liked robotics but now I know that I really love it!" • "This experience made me like technology even more!" • *Must be clear that they liked it prior to this and this increased liking. Response includes strong feeling or emotion.*
105 Don't enjoy technology • Specifically mention disliking robots, robotics, technology, or computers. • "I like technology less now." • "I don't like robots."	
102 Boring • Any mention of boring • "Technology is boring" • "It was boring" • "Boring parts"	**202 Interest** • General statement of interest in or increased interest in robotics, technology, etc. • "Robots are interesting" • "I became interested in robotics" • "It made technology seem less boring" • "It opened up a new type of technology to explore" • "I am now more interested in robotics." • "I've always been interested in this"

	• "Yes because it will increase their interest in technology" • "They will become interested in robots" • "It looks interesting" • "It was interesting"
103 Too much time • "We spent too long on it"	
106 Don't enjoy class topic • "I don't like poetry (or subject area)"	**206 Enjoy class topic** • They like or enjoy the class topic. Note this is different from learning about the class topic. See "Disciplinary Learning" below. • "I like poetry"
107 Dislike arts and crafts • "I don't like arts and crafts"	**207 Like arts and crafts** • "I like arts and crafts"
	208 Enjoy building • They like building and hands-on activities. • Verbs: building, putting it together, making • "I like hands on activities" • "I liked putting it together" • "It was fun <u>making</u> robots" • "Making robots is fun" • "I liked building the project" • "It is hands on" • "Building the project is fun"
C1 -	**C2 –**
127 Hard • *Are you excited to do this project? (Said they thought it would be hard.)* • *Did you enjoy doing this project? (Said they didn't enjoy it because it was hard.)* • *Should other students have this experience? (Said no because it was hard.)* • *Do you have any suggestions for improvements? (Said it was too hard.)* • *What was the best thing that you learned during the project? (Noted that it was hard. Decide later if we want to differentiate between technology is hard and the experience is hard based on the responses. Total category size may be small and not worth splitting.)* • ***Not for:** How did this experience change how you think about technology? (Go under Appreciation)* • Hard, confusing, or difficult • They just say it is hard but don't say there was a greater value to it as in the "Enjoyable challenge" category. • Can be technology or the experience that is hard.	**227 Easy or Less Challenging** • "Less complicated than I expected" • "less confusing than I thought" • "technology is easier than it looks" • "it[experience] made it[technology] easier" • "Technology is simple to use" • "It can be easy to learn" • "It was easy", "It is easy" • Focus is on ease of use rather than students' abilities. • Students said technology was easy or less challenging than they expected. • (By "it was easy" you would be unlikely to mean the project was easy but technology is hard since technology is a primary component of the project, so there is just one Easy category not a project is easy and a technology is easy split.)

• “Programming is hard work” • “No, robotics takes a lot of time and effort.” • “Technology can be confusing” • “I got confused.” • “It [technology] is hard” • “It seems like a lot of work.” *(Are you excited…?)*	
120 Inexperience • “I don’t have any experience with this” • “I don’t know how to do this” • “I only worked on the art” • Inexperience is negative (vs Novelty is positive)	**Easier than I thought :** **220 Increased Confidence** • Increased confidence or more skill • “I thought it was way too complex for me to learn, but I can actually do it” • “it made me feel more confident” • “It increased my confidence with technology and robotics” • “I can do it” • “It improves confidence with technology and robotics” • “Everybody can do it no matter how smart they are” • “Once you learn about it, it’s not really that hard” • “I think I will do well” • “The best thing I learned was how to use the technology and it’s not as hard as I thought.” – Note I tried not to count these as two. If they said they learned to use technology and it wasn’t as hard as expected I just counted it as Confidence. • Students said it increased their confidence with technology.
	E2 - There is more to Technology than Technology
	209 Appreciation for the broader applicability of technology • Increased general technology/robotics appreciation. • Learned about *the uses of technology* (vs using tech – that would be “Technical Learning” instead). • Appreciation for technology in the world at large. • Appreciation for the broader applications of technology. • Expresses awe and amazement with technology • “It increases appreciation for technology” • “It gives you a better perspective of robotics” • “The connection between robots and everyday life” • “You can program a robot to do anything you want” • “I now know there is more to technology than meets the eye” • “I see how technology can be used in my life” • “You can do lots of things with technology” • “It plays an important role in our lives” • *More general than Multidisciplinary*

	204 Appreciation for the complexity of technology • *For How did this experience change….? All “Hard” answers are Appreciation for complexity.* • Increased understanding for *the complexity* of technology or *time required* to do technology. • “technology is harder than it looks” • “more complicated than I expected” • “it takes more time than I thought” • “I thought it would be easy, but it actually took some work” • “I realized how difficult it was” • “It takes time to create”, “Technology takes time” • “Robotics take a lot of time and effort.” (For How did this change…?) • “It makes me appreciate how hard it is to program something” • Learn what is involved in technical jobs. • Includes understanding for what others do for their technical careers: “I understand what programmers have to do for their job.”, “I understand technical careers better” o *Also For ”What is the best thing you learned…”* • *Note: if we find more than 1 or 2 that can’t be clearly put in 209 or 204, we can collapse this code. If you find one that you can’t distinguish, assign code 209 but mark it. [1% of 247 is 2.47]*
	210 Multidisciplinary / Creative • This is close to Appreciation for Technology, but specifically mentions combining robots and other disciplines. • Does not mention learning or understanding the discipline. • “Robotics and poetry go surprisingly well together” • “Using technology can make learning about poetry fun” • “technology can increase my knowledge in other fields” • “It was multidisciplinary” • Mention the creative nature of the project or technology • “I can express myself with technology” • “Technology can be used to tell a story” • “Robotics can be creative” • “It encouraged me to be creative” • “It made me realize that technology requires creativity” • “there is a creative aspect to technology” • “I will get to be creative” • “It encourages creativity”

	• "They can express themselves" • Counter example: This is not "I like robots and I like poetry". • *More specific than Appreciation.*
122 Didn't learn anything • "Nothing" – For "Best thing you learned?"	**222 Disciplinary learning** • Learning about or improved understanding of the class topic (poetry, anatomy, history, Shakespeare, science, specific art concepts, etc.). • It is a good way to learn about the class topic. • "It is a good way to learn poetry" • "I enjoyed this method of learning poetry" • "Helped me understand the poem better" • "They will learn about literature" • "Making a robot helped me to understand how bones move"
F1 - Poor Learning Experience	**F2 - Learning / Unsatisfied curiosity**
121 Curricular or instructional problems • more explanation, improve curriculum or instruction • "Directions were not clear" • "There was not enough instruction" • "Explain more on servos and hummingbird" • "Explain how to program better" • "Create an example project presentation with step by steps" • "Needed better directions"	**221 Technical learning** • Any technical learning. Desire to learn or learning about robots, technology, electronics, programming, or computers. • **Increased understanding of technology in general.** • **Learned a specific technical skill.** • Also includes self-reported learning about technology (vague and specific) • *Using* technology (but not uses of technology – that would be Appreciation for Technology instead) • "Programming the hummingbird" • "I learned how to build a robot" *(Note: Technical Learning gets priority over building.)* • "Programming is more about timing than anything else" • "motors" • "mechanics" • "I understand it better." • "I want to learn about robots" • "They get to work with robots" • "I understand it better" • "how to use LEDs" • "I learned how to program" • "how to program robots" • *Note: This does not include new perspectives about robots [This is in Appreciation for Technology]* • *Note: The Learning category gets priority over the fun/enjoyment category if they are balanced in the response.*
123 Negative learning experience • A bad learning experience, not specific to the above categories (Curricular Instruction or Not Learning Anything)	**223 Vague learning** • "I want to learn something new" • "It was an enjoyable learning experience" • "I learned something new"

• "It was a waste of time" • "It was a bad learning experience"	• "It is a positive learning experience" • "It is educational" • Note: *Learning* takes priority over *new* in the case of "I learned something new" or "I want to learn something new." *Learning* takes priority over *fun* in the case of "How to make learning fun" or "Learning can be fun." "It is fun to <u>learn</u> something new"
	225 Grasp of Designing Systems • Quotes related grasp of the design process or complexity of systems engineering • "Technology requires an engineering design process." • "The best thing that I learned during this project was that creating different parts of the project is easy, but puting them together is harder." • "The best thing that i learned during the project was how all the parts have to work in harmony in order for the robot to work to the best ability." • "Never count of the first idea or way you first had the project. You will change that idea really quick." • "once you think of something it completely changes into a more modified version of it."
	224 My Career • Learning for or about their career or future beyond this class. (Or other's career for "Should other students…") • "It will help me with my career" • "I will use what I learned in the future" • "I would like to practice in this field" • "It will be helpful for their career" • "It will be useful in the future" • "It will help them decide if they like robotics" • Note: *Understanding* what *others* do for their career is Appreciation for complexity of technology (for How did this experience change…?)
G1 - Wrong Level of Difficulty	**G2 - Appropriate Level of Difficulty – Got something good out of the challenge**
128 Stressful • Causes worry or anxiety	**228 "Stressful but good"** • Mention that it was stressful, but at the same time it was beneficial or positive. • "It is stressful but good" • "Though it was stressful at times, it paid off in the end."
129 Frustrating • Causes anger or annoyance • "It is frustrating"	**229 Enjoyable or good challenge** • Mention that it was hard or challenging but at the same time it was fun, good, or rewarding. • Difficult in a way that is interesting or enjoyable. • "Technology is difficult but it pays off"

	• "It is a good challenge" • "It's an enjoyable challenge" • "I enjoyed the challenge" • "Technology is fun but hard" • "Technology is fun but challenging" • "It can be difficult but fun" • "It is hard but rewarding" • "Working with technology can be hard, but is rewarding"
	230 Perseverance • Perseverance: The quality that allows someone to continue trying to do something even though it is difficult. • The value of hard work • "It teaches perseverance" • "It requires determination" • "It requires commitment" • "How to work hard" • "You have to work hard to get everything done"
	231 Problem solving • "I learned problem solving skills" • "It improves problem solving skills"
132 Not enough time • "Give more time"	**232 Time management** • "They will learn time management"

	212 Patience with technology
	• "It teaches patience with technology"
	• "I learned to be more patient with it [technology]"
	• "Technology requires patience"
	• Note: Not "Technology takes time"
	  ○ For How did this experience change how you think about technology? This goes under *Appreciation* for complexity of technology because they do not say they gained patience.
	  ○ For What is the best thing you learned? This goes under *Hard*.

H1 - Technical problems	
112 School-related technical problems • Trouble with computers or network • Program/software wouldn't install or launch • "Use better computers"	
113 Software problems • Program/software crashed • "Make expressions easier to use"	
114 Hardware problems • Hummingbird didn't work • Parts broke	

• "More durable vibrator motors." • "Better tools and equipment"	
115 More Hardware • Request more hardware parts	
116 Problems with non-technical resources • Non-technical resources (classroom size, craft material choice) • Improve craft or construction materials • "More space" • "Use good tape."	
117 More classroom supplies • Request more non-technical parts • "more materials"	
135 Vague technical problems • Complain of technical problems, but the source (hardware, software, computers) can't be determined.	
118 Lack of novelty • "It was the same thing I had done before" • "We had already done this project last year" • "Make it different from what we did last year" • *How did this change…?* "It didn't because I've done this before." Gets a 3 (it didn't) and this code for lack of novelty.	**218 Novelty** • Excited to do something new or different • Break from regular class work or testing • "It was new", "It is something new" • "It was different" • "It was better than normal class work" • Note: *Learning* takes priority over *new* in "I want to learn something new", so this would be the Vague Learning category instead. • Note: *Try not to double code the fun in fun prior experience.*
119 Prior negative A&B experience • "I didn't like Arts & Bots last time."	**219 Prior positive A&B experience** • "I liked Arts & Bots last time" • "I liked it last year" • "I liked it before" • Note: This is not "I like this sort of thing." – goes in Fun and Enjoyment • Note: This is not "Yes, I've worked with robots before" – goes in "Enjoy Technology" instead
133 Increase the challenge • Increase the complexity, difficulty or challenge. • "Make more requirements to make the students work harder."	
126 Negative teamwork • Expresses a purely negative view of teamwork. • "You can't count on your team mates." • "It is hard working in groups" • "Don't work in teams"	**226 Teamwork** • "I liked working in a group" • "It improves teamwork skills" • "It teaches you how to work in a team"

134 Dissatisfaction with the outcome	**234 Satisfaction with the outcome** • I will be satisfied with the outcome • "I like how our robot turned out" • "I enjoyed completing the project"
150 Unique negative • Negative responses that are a distinct idea clearly not included in the codes above. • Note this is not a vague answer.	**250 Unique positive** • Positive responses that are a distinct idea clearly not included in the codes above. • Note this is not a vague answer. • *For Best thing Learned: They learned something else not captured by our code.*

3 How did this experience change…?	**3 – No change reported** • They report no change • "It didn't" • "none" • "not much" • Note: Can code the "no change" (3) and the <u>reason</u> or <u>explanation</u> with a second code if one applies. If they say "no change" but then list an actual change (not a reason), just code the change and do not assign a 3.
3 Are you excited?	**3 – Mixed or neutral response** • If Mixed: Code with a 3, and then code the specific positive and negative parts with the code from above.
3 Should others?	**30 Maybe** **31 Students should be allowed to choose** **32 Only deserving students should be allowed** • "No, Other people will break something" • Only people with good enough grades should be allowed to do it. • Only those who have earned it

<table>
<tr><th colspan="2">Negative</th><th colspan="2">Positive</th></tr>
<tr><td>100 Vague negative</td><td colspan="2">300 Vague indeterminate</td><td>200 Vague positive</td></tr>
<tr><td colspan="2">B1 - Disliking</td><td colspan="2">B2 - Liking</td></tr>
<tr><td colspan="2">101 Not fun or Dislike (not specific)</td><td colspan="2">201 Fun and Enjoyment (general or technology)</td></tr>
<tr><td colspan="2">105 Don’t enjoy technology</td><td colspan="2">205 Now I like it even more! (Special case. Assign in addition to 201)</td></tr>
<tr><td colspan="2">102 Boring</td><td colspan="2">202 Interest</td></tr>
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<tr><td colspan="2">122 Didn’t learn anything</td><td colspan="2">222 Disciplinary <u>learning</u></td></tr>
<tr><td colspan="2">F1 - Poor Learning Experience</td><td colspan="2">F2 - Learning / Unsatisfied curiosity</td></tr>
<tr><td colspan="2">121 Curricular or instructional problems</td><td colspan="2">221 Technical learning</td></tr>
<tr><td colspan="2">123 Negative learning experience</td><td colspan="2">223 <u>Vague</u> learning</td></tr>
<tr><td colspan="2"></td><td colspan="2">225 Grasp of Systems Engineering</td></tr>
<tr><td colspan="2"></td><td colspan="2">224 My Career</td></tr>
<tr><td colspan="2">G1 - Wrong Level of Difficulty</td><td colspan="2">G2 - Appropriate Level of Difficulty – Got something good out of the challenge</td></tr>
<tr><td colspan="2">128 Stressful</td><td colspan="2">228 “Stressful but good”</td></tr>
<tr><td colspan="2">129 Frustrating</td><td colspan="2">229 Enjoyable or good challenge</td></tr>
<tr><td colspan="2"></td><td colspan="2">230 Perseverance</td></tr>
<tr><td colspan="2"></td><td colspan="2">231 Problem solving</td></tr>
<tr><td colspan="2">132 Not enough time</td><td colspan="2">232 Time management</td></tr>
<tr><td colspan="2"></td><td colspan="2">212 Patience with technology</td></tr>
<tr><td colspan="2">H1 - Technical problems</td><td colspan="2"></td></tr>
<tr><td colspan="2">112 School-related technical problems</td><td colspan="2"></td></tr>
<tr><td colspan="2">113 Software problems</td><td colspan="2"></td></tr>
<tr><td colspan="2">114 Hardware problems</td><td colspan="2"></td></tr>
<tr><td colspan="2">115 More Hardware</td><td colspan="2"></td></tr>
<tr><td colspan="2">116 Problems with non-technical resources</td><td colspan="2"></td></tr>
<tr><td colspan="2">117 More classroom supplies</td><td colspan="2"></td></tr>
<tr><td colspan="2">135 Vague technical problems</td><td colspan="2"></td></tr>
<tr><td colspan="2">118 Lack of novelty</td><td colspan="2">218 Novelty, new, different</td></tr>
<tr><td colspan="2">119 Prior negative A&B experience</td><td colspan="2">219 Prior positive A&B experience</td></tr>
<tr><td colspan="2">133 Increase the challenge</td><td colspan="2"></td></tr>
<tr><td colspan="2">126 Negative teamwork</td><td colspan="2">226 Teamwork</td></tr>
<tr><td colspan="2">134 Dissatisfaction with the outcome</td><td colspan="2">234 Satisfaction with the outcome</td></tr>
<tr><td colspan="2">150 Unique negative</td><td colspan="2">250 Unique positive</td></tr>
</table>

0	**Non-Answer**

	Do you have any suggestions for improvements?
2 Do you have any suggestions…?	**No** **21** [blank] or "I don't know" **23** No **24** No, with more explanation
1 Do you have any suggestions…?	**Yes** **100** Yes [Vague negative] **101** Don't do this project [Dislike, not specified] **106** Change the class topic [Don't like topic] **13** More personal choice within topic **14** Make it available outside of school Other codes from Category (1) below can also be used.
3 Do you have any suggestions…?	**3 Other** • Advise to other students that really doesn't fit another category

3 How did this experience change…?	**3 – No change reported** • They report no change • "It didn't" • "none" • "not much" • Note: Can code the "no change" (3) and the reason or explanation with a second code if one applies. If they say "no change" but then list an actual change (not a reason), just code the change and do not assign a 3.
3 Are you excited?	**3 – Mixed or neutral response** • If Mixed: Code with a 3, and then code the specific positive and negative parts with the code from above.
3 Should others?	**30 Maybe** **31 Students should be allowed to choose** **32 Only deserving students should be allowed** • "No, Other people will break something" • Only people with good enough grades should be allowed to do it. • Only those who have earned it

Merriam-Webster.com definitions

- Interesting:
  - Simple Definition:
    - :attracting your attention and making you want to learn more about something or to be involved in something : not dull or boring
  - Full Definition:
    - : holding the attention : arousing interest
- Boring:
  - Simple Definition:
    - : dull and uninteresting : causing boredom
  - Full Definition:
    - : causing boredom : tiresome
    - Boredom: Full Definition : the state of being weary and restless through lack of interest
- Interest:
  - Simple Definition:
    - : a feeling of wanting to learn more about something or to be involved in something
    - : a quality that attracts your attention and makes you want to learn more about something or to be involved in something
  - Full Definition:
    - 5 a: a feeling that accompanies or causes special attention to an object or class of objects : concern
- Enjoy:
  - Simple Definition:
    - : to take pleasure in (something)
    - : to have or experience (something good or helpful)
  - Full Definition:
    - 2: to take pleasure or satisfaction in
- Like:
  - Simple Definition:
    - : to enjoy (something) : to get pleasure from (something)
    - : to regard (something) in a favorable way
  - Full Definition:
    - 2 a: to feel attraction toward or take pleasure in : Enjoy
- Dislike:
  - Simple Definition:
    - : a feeling of not liking or approving of something or someone
    - : something that you do not like, approve of, or enjoy
  - Full Definition:
    - A feeling of aversion or disapproval
- Fun:
  - Simple definition:
    - : someone or something that is amusing or enjoyable : an enjoyable experience or person
    - : an enjoyable or amusing time
    - : the feeling of being amused or entertained
  - Full Definition:
    - 1: what provides amusement or enjoyment; specifically : playful often boisterous action or speech
    - 3 a: amusement, enjoyment

Thesaurus.com (Roget's 21st Century Thesaurus, Third Edition Copyright © 2013 by the Philip Lief Group)

- First antonym for fun is boring

- Second antonym listed for <u>enjoyable</u> is <u>boring</u>.

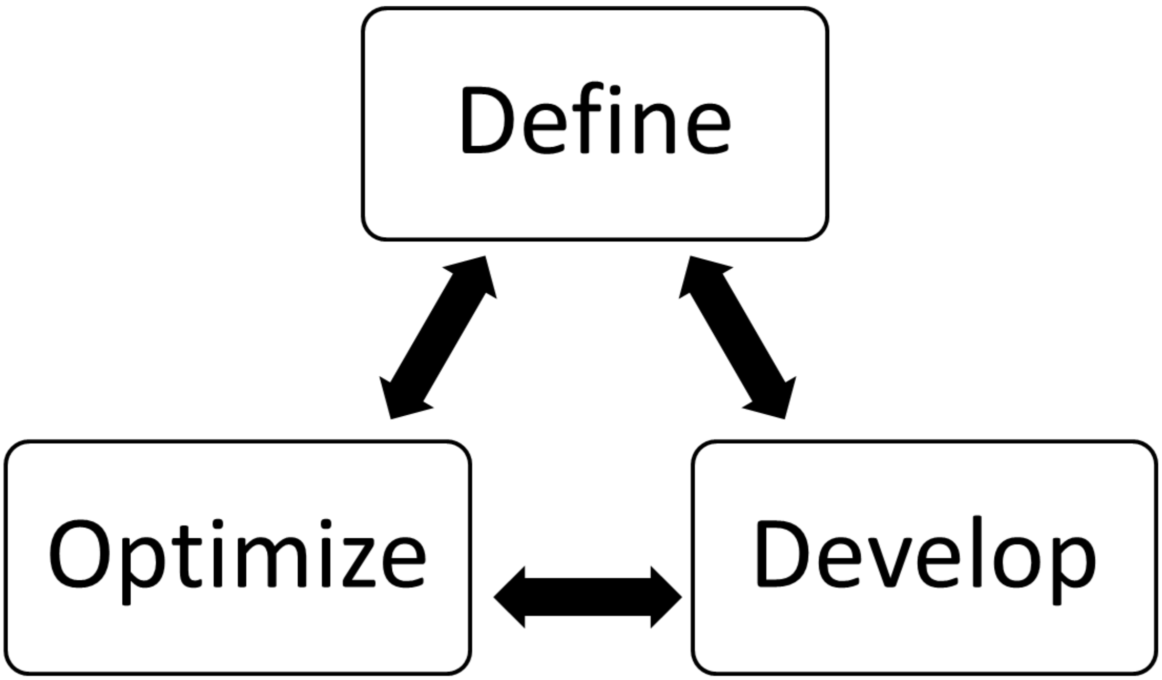
So based on Merriam-Webster definitions interest and interesting would be the opposite of boring. Enjoy, like, and fun would be the opposite of dislike. Including relationships from the thesaurus, boring is also an opposite for fun and enjoyable.

- Perseverance
    - Simple Definition of perseverance
        - : <u>the quality that allows someone to continue trying to do something even though it is difficult</u>
    - Full Definition of perseverance
        - : continued effort to do or achieve something despite difficulties, failure, or opposition : the action or condition or an instance of persevering : steadfastness
- Challenging
    - Simple Definition of challenging
        - : <u>difficult in a way that is usually interesting or enjoyable</u>
    - Full Definition of challenging
        - 1: arousing competitive interest, thought, or action <a challenging course of study>
        - 2: invitingly provocative : fascinating <a challenging personality>
- Frustrating
    - Simple Definition of frustrating
        - : causing feelings of <u>anger and annoyance</u>
    - Full Definition of frustrating
        - : tending to produce or characterized by frustration <a frustrating delay>
- Frustration
    - Simple Definition of frustration
        - : a feeling of <u>anger or annoyance</u> caused by being unable to do something : the state of being frustrated
        - : something that causes feelings of anger and annoyance : something that frustrates someone
        - : the act of preventing the success of something : the act of frustrating something
    - Full Definition of frustration
        - 1: the act of frustrating
        - 2a : the state or an instance of being frustrated b : a deep chronic sense or state of insecurity and dissatisfaction arising from unresolved problems or unfulfilled needs
        - 3: something that frustrates
- Stressful
    - Simple Definition of stressful
        - : full of or causing stress : making you feel <u>worried or anxious</u>
    - Full Definition of stressful
        - : full of or tending to induce stress
- Hard
    - Simple Definition
        - : physically or mentally difficult : not easy
- Easy
    - Simple Definition
        - : not hard to do : not difficult
        - : free from pain, trouble, or worry

Appendix H: Student Design Notebook with NGSS Reference

Arts & Bots

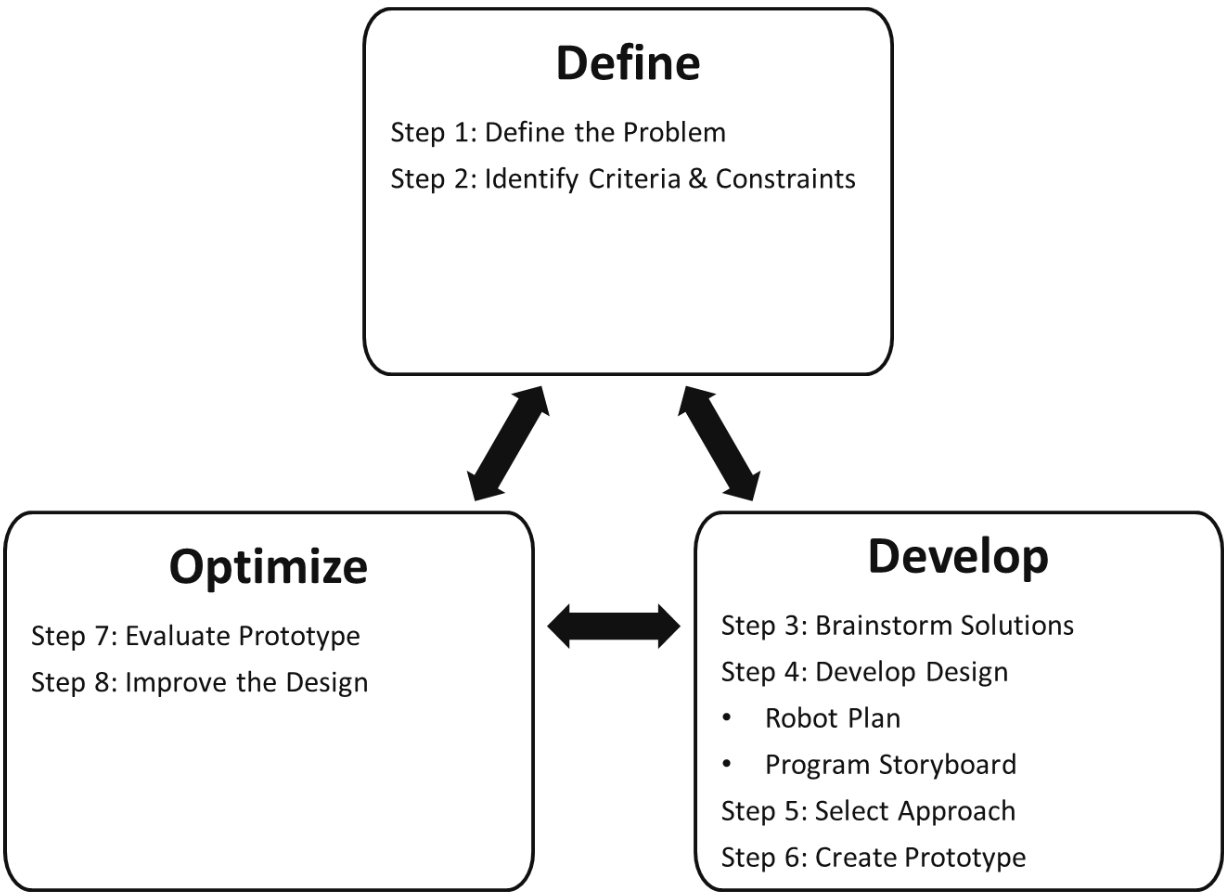
Design Notebook



THIS NOTEBOOK BELONGS TO:

DATE:

Engineering Design Process Steps



Date: ________________________________

Define

STEP 1: DEFINE THE PROBLEM OR GOAL

What do you want your robot to look like?

What do you want your robot to be able to do?

Do you have any other goals for your robot?

Date: ________________________________

Define

STEP 2: IDENTIFY CRITERIA AND CONSTRAINTS

What are your criteria for success? How will you decide if the robot meets your goals?

What constraints limit your design?

Assignment Requirements:

Materials:

Time:

Other:

Date: ______________________________

Develop

STEP 3: BRAINSTORM SOLUTIONS

Brainstorm, sketch and/or list your ideas for making a robot to meet these goals:

Date: ________________________________

Develop

STEP 3: BRAINSTORM SOLUTIONS

Brainstorm, sketch and/or list your ideas for making a robot to meet these goals:

Date: ________________________________

Develop

Design Number

______

STEP 4: DEVELOP DESIGN—ROBOT PLAN

What will your robot look like? What materials will you need?

Date: ________________________________

Develop

Design Number

____

STEP 4: DEVELOP DESIGN—PROGRAM STORYBOARD

Expression #______

Expression #______

Expression #______

Expression #______

Expression #______

Expression #______

Date: ________________________________

Develop

STEP 5: SELECT APPROACH

Which design will meet your goals best? Does it match your constraints?

What are the pros and cons of the designs?

Select which design to create: Design Number __________

Date: ______________________________

Develop

STEP 6: CREATE A PROTOTYPE

Build your robot prototype. You may need to test parts and revise your designs as you build.

How is the robot different from your design plan?	Why did you make that change?

What materials and parts did you use ?

Date: ______________________________

Optimize

STEP 7: EVALUATE THE PROTOTYPE

How well does your robot meet your goals and criteria ?

What works? Which goals did you meet?	What does not work? Which goals were not met?

Date: ______________________________

Optimize

STEP 8: IMPROVE THE DESIGN

What could work better? How could you meet your remaining goals?

Connecting to the Next Generation Science Standards

Define	Develop	Optimize
ETS1.A	**ETS1.B**	**ETS1.C**

Middle School Engineering Design from Next Generation Science Standards

Students who demonstrate understanding can:

MS-ETS1-1. Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.

MS-ETS1-2. Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.

MS-ETS1-3. Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.

MS-ETS1-4. Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved.

The performance expectations above were developed using the following elements from the NRC document A Framework for K-12 Science Education:

SCIENCE AND ENGINEERING PRACTICES

Asking Questions and Defining Problems

Asking questions and defining problems in grades 6–8 builds on grades K–5 experiences and progresses to specifying relationships between variables, and clarifying arguments and models.

- Define a design problem that can be solved through the development of an object, tool, process or system and includes multiple criteria and constraints, including scientific knowledge that may limit possible solutions. (MS-ETS1-1)

Developing and Using Models

Modeling in 6–8 builds on K–5 experiences and progresses to developing, using, and revising models to describe, test, and predict more abstract phenomena and design systems.

- Develop a model to generate data to test ideas about designed systems, including those representing inputs and outputs. (MS-ETS1-4)

Analyzing and Interpreting Data

Analyzing data in 6–8 builds on K–5 experiences and progresses to extending quantitative analysis to investigations, distinguishing between correlation and causation, and basic statistical techniques of data and error analysis.

- Analyze and interpret data to determine similarities and differences in findings. (MS-ETS1-3)

Engaging in Argument from Evidence

Engaging in argument from evidence in 6–8 builds on K–5 experiences and progresses to constructing a convincing argument that supports or refutes claims for either explanations or solutions about the natural and designed world.

- Evaluate competing design solutions based on jointly developed and agreed-upon design criteria. (MS-ETS1-2)

DISCIPLINARY CORE IDEAS

ETS1.A: Defining and Delimiting Engineering Problems

- The more precisely a design task's criteria and constraints can be defined, the more likely it is that the designed solution will be successful. Specification of constraints includes consideration of scientific principles and other relevant knowledge that are likely to limit possible solutions. (MS-ETS1-1)

ETS1.B: Developing Possible Solutions

- A solution needs to be tested, and then modified on the basis of the test results, in order to improve it. (MS-ETS1-4)
- There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem. (MS-ETS1-2), (MS-ETS1-3)
- Sometimes parts of different solutions can be combined to create a solution that is better than any of its predecessors. (MS-ETS1-3)
- Models of all kinds are important for testing solutions. (MS-ETS1-4)

ETS1.C: Optimizing the Design Solution

- Although one design may not perform the best across all tests, identifying the characteristics of the design that performed the best in each test can provide useful information for the redesign process—that is, some of those characteristics may be incorporated into the new design. (MS-ETS1-3)
- The iterative process of testing the most promising solutions and modifying what is proposed on the basis of the test results leads to greater refinement and ultimately to an optimal solution. (MS-ETS1-4)

CROSSCUTTING CONCEPTS

Influence of Science, Engineering, and Technology on Society and the Natural World

- All human activity draws on natural resources and has both short and long-term consequences, positive as well as negative, for the health of people and the natural environment. (MS-ETS1-1)
- The uses of technologies and limitations on their use are driven by individual or societal needs, desires, and values; by the findings of scientific research; and by differences in such factors as climate, natural resources, and economic conditions. (MS-ETS1-1)

This table was reproduced from the Next Generation Science Standard on February 2014.

Disciplinary Core Ideas and Grade 8 Endpoints

DEFINE

What is a design for?
What are the criteria and constraints of a successful solution?

By the end of grade 8: The more precisely a design task's criteria and constraints can be defined, the more likely it is that the designed solution will be successful. Specification of constraints includes consideration of scientific principles and other relevant knowledge that are likely to limit possible solutions (e.g., familiarity with the local climate may rule out certain plants for the school garden).

DEVELOP

What is the process for developing potential design solutions?

By the end of grade 8: A solution needs to be tested, and then modified on the basis of the test results, in order to improve it. There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem. Sometimes parts of different solutions can be combined to create a solution that is better than any of its predecessors. In any case, it is important to be able to communicate and explain solutions to others.

Models of all kinds are important for testing solutions, and computers are a valuable tool for simulating systems. Simulations are useful for predicting what would happen if various parameters of the model were changed, as well as for making improvements to the model based on peer and leader (e.g., teacher) feedback.

OPTIMIZE

How can the various proposed design solutions be compared and improved?

By the end of grade 8: There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem. Comparing different designs could involve running them through the same kinds of tests and systematically recording the results to determine which design performs best. Although one design may not perform the best across all tests, identifying the characteristics of the design that performed the best in each test can provide useful information for the redesign process—that is, some of those characteristics may be incorporated into the new design. This iterative process of testing the most promising solutions and modifying what is proposed on the basis of the test results leads to greater refinement and ultimately to an optimal solution. Once such a suitable solution is determined, it is important to describe that solution, explain how it was developed, and describe the features that make it successful.

Prompt questions and grade band endpoints reproduced verbatim from:

National Research Council (NRC) 2012. A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas. Committee on a Conceptual Framework for New K-12 Science Education Standards. Board on Science Education, Division of Behavioral and Social Sciences and Education. Washington, DC: The National Academies Press.

Appendix I: Teacher Tip Sheet

Tips for Using Arts & Bots
By Arts & Bots Teachers

Lesson Planning & Before Building

- Build a school support structure - hives of passionate teachers
- Decide on a unit
  - Choose a topic that you or your students struggle with
  - Choose a topic or project that you are comfortable teaching
- Do topic/content research before the starting robots to build background and give students ideas
- Have custom / recorded sounds saved before programming
- If you share equipment, consider when you will have access and how that will fall in your overall schedule to pick an appropriate topic.
- Send a materials list home about one month ahead of time
- Get in contact with Carnegie Mellon research team, one month prior to starting the build to get all paperwork turned in to the appropriate people.
- Have students pick out materials before the build
- Use the design booklet from Arts & Bots to help the students plan
- Remember to do the pre-survey
- If using rubrics to evaluate students and projects, give to students before the build to know the expectations.
- Between first and second implementation, you will learn a lot of little things.
- End of the year can be more difficult for scheduling with students being pulled out of class for testing, etc.
- Consider the timing of the project - older students are more mature and later in the year, the class community structure is better defined, younger sixth graders are sometimes better at following instructions that older sixth graders
- Students who need more help are the ones who demonstrate less talent, how do you make sure the talented students are getting cultivation - build in extra credit tasks and advanced levels into the grading rubric
- Assign a student helper, perhaps from a more advanced grade or prior class, to help with laptops
- Train 5 students after school to help during the programming stage (approximately two weeks before the build)
- Schedule help during the build
- Have demonstration / sample robots or videos ready before the project to show to students to set expectations.
- Model for the students how to connect the wires to the hummingbird
  Show students or give them links to the videos at: www.hummingbirdkit.com/learning/tutorials

Setup & Organization

- Be aware of shared resources and materials, like laptops, check that they are ready before project start.
- Check the kits before the build to make sure you do not have missing
- Model putting the silver bags back in the kit, so it does not get lost
- Instead of complete individual Hummingbird kits, repackage all the components into parts bin
    - Have a “Servo” bin, “Motor” bin, “Sensors” bin, “LED and Tri-Color LED” bin, “Hummingbird” bin, etc. with photos and names to help students find parts easily, make clean up fast and avoid having poorly rebuilt/repackaged kits next time
- Have containers for each group's project (tubs or cardboard boxes, etc) for storing robots, materials and designs in progress between class sessions – stack them in the back of classroom during other classes
- Encourage students to clean up their workshop by giving a score or a few points daily for end of class clean up participation.

Tools

- Consider the room setup - locations of power plugs for students, table setups, adequate space for large projects, where materials are stored between class sessions.
- Evaluate power sources and need for extension cords (each team will need two outlets nearby)
- Give students utility scissors for cutting heavy materials instead of knives
    - Like these: http://www.adafruit.com/products/1599
    - Extra "real" heavy duty scissors and not weak school scissors
- Have someone to man the glue guns or a plan for using them
- Have a plan in place for handling Exacto knife and box cutter
- Get a few wire strippers and wire cutters for “fixing” the ends of previously used components
- Computers
    - Check computers to see if an admin log in is needed to store files and install software on the computer
    - Check to see if your computer will recognize the Hummingbird if you have a Smart Slate or receiver to a Smartboard (I had to unplug everything)
    - Have a plan for charging laptops between classes
    - See if computers have automatic system updates for Windows and Java
    - Make sure the laptops have Java installed on them
    - If you don’t have a tech support person at your school who can prepare computers for you, consider asking a tech savvy student volunteer to help set up computers. For example, before you are scheduled to begin, you will want to be sure that computers are charged and software is up to date.
    - Be aware of shared resources and materials, like laptops, check that they are ready before project start.

- Assign a student helper, perhaps from a more advanced grade or prior class, to help with laptops
- Dedicated computers or computers that are easy to access
- Can you install software? Do you have administrative passwords?
- Support by internet - can you access online tutorials? Surveys?
- Turn around time for tech support requires - local vs remote support

Teams

- Methods for forming teams are important, consider skill levels, genders, social interactions, motivation, etc.
- Consider group sizes for team - account for possible absent students.
- Three students works well … two is too small if someone is absent, four is too many and someone is always off task
- Consider groups of absent students (sports team all missing the same class)
- Having students make up time separate from teams can cause negative progress (poor communication between students)
- Help students scaffold their team activities and manage their project BEFORE the building starts
    - Decide how many steps or rolls exist for the project team
    - Have students decide on assigned rolls between students
    - Encourage students to give their teammates constructive feedback part way through the build
    - Include "teamwork scoring" on the rubric where students are asked to evaluate their teammates and self-evaluate on contributions to the project during their project reflection

During the Build and Programming

- The first day with software and hardware instruction are critical
    - If there are many absentees during software and hardware instruction, it is important to redo that lesson for their make-up … cannot just learn software and hardware from teammates.
    - Have a plan in place for making up missed hardware and software lessons, send home links to video tutorials as homework / flipped classroom.
- Modify schedule if possible
- Students need to feel urgency in the project so they stay on task, schedule in an extra build day but don't tell the students until the last day so they have time to add finishing touches.
- Assign groups a kit number & computer that they wlll have during the entire build
- Decide whether or not students will be allowed to paint robots
- Assemble the robot and place motors, servos, etc in the robot without glue first
- Need one or more extra hands, but lots of hands add extra confusion
- Have something for the other groups to work on while you help each group learn to program

- Motors and servos may need to be glued and glued again numerous times to get positions correct
- Some type of signal to get students attention in the midst of building
- Instruct the students on where to save their teams files on the computer
    - Save files on a team USB jump drive in case they need to use different computers or accounts
    - Leave the USB flash drive with the robot, if the person who is usually programming is absent – the team can still get to their files
- If the servo or large motors do not work, it may be because of missing power supply (only motors need AC electricity)
- Is there a support person or student volunteer for help taking apart robots and rebuilding kits

List of Figures

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