**Paper Title** Robots and Romeo and Juliet: Studying Teacher Integration of Robotics Into Middle School Curricula

**Author(s)** Debra Bernstein, TERC; Karen Mutch-Jones, TERC; Emily Hamner, Carnegie Mellon University; Jennifer Light Cross, Carnegie Mellon University

**Session Title** Science and Inquiry in Technology-Based Learning Environments

**Session Type** Paper

**Presentation Date** 4/8/2016

**Presentation Location** Washington, D.C.

**Descriptors** Technology

**Methodology** Qualitative

**Unit** Division C - Learning and Instruction

# Robots and Romeo and Juliet: Studying Teacher Integration of Robotics into Middle School Curricula

**Debra Bernstein**[1] (TERC), **Karen Mutch-Jones** (TERC), **Michael Cassidy** (TERC), **Emily Hamner** (Carnegie Mellon University), **Jennifer Cross** (Carnegie Mellon University)

## Abstract

*To increase opportunities for more students to engage in technology innovation, the Creative Robotics project supports robotics integration into disciplinary classrooms. The project provides professional development and resources to teachers in non-technical subjects (e.g., health, science, English), while enabling them to develop their own instructional strategies for integrating the Arts & Bots approach. A study of pedagogical and instructional approaches of 15 teachers during the project's first year suggests that teachers used Arts & Bots as a tool to support student learning to: (1) facilitate translation of abstract disciplinary concepts into concrete exemplars; (2) increase exposure to disciplinary material; or (3) increase familiarity with technology. This research underscores the importance of integrated curricula that consider disciplinary needs and technological affordances*.

## Introduction

Robots are becoming increasingly familiar in K-12 education. However, access to robotic technology is often limited to students in a subset of STEM-related courses (Benitti, 2012). The Creative Robotics project integrates design-based robotics into classrooms across a range of disciplines, including science, health, English/language arts, and social studies, and it provides opportunities to study changes in practice as teachers make instructional and curricular decisions to support disciplinary learning and technology innovation.

Creative Robotics utilizes the Arts & Bots approach—a classroom robotics kit which provides motors, sensors, lights, and a microprocessor that can be controlled with a custom visual programming language (Hamner & Cross, 2013; Cross, Bartley, Hamner, & Nourbakhsh, 2013), and craft materials to build a robot and attach components. Arts & Bots provides a flexible base for a range for robotic design activities.

Between 2013 and 2015, the Creative Robotics project trained 15 middle school teachers in two school districts (one rural, one suburban) to design and implement discipline-based robotics curricula. During the two-day professional development seminar teachers learned to build and program robots, and teacher educators led discussions about integrating robotics into disciplinary curricula (Hamner et al., 2016). Teachers were also given pedagogical tools to support robotics design activities, such as student design notebooks and storyboard templates. However, teachers were free to select the curricular topic and develop their own strategies for integrating Arts & Bots activities. While this allowed them to customize their instructional approach to ensure

[1] Corresponding author: Debra Bernstein, TERC, 2067 Massachusetts Avenue, Cambridge, MA, 02140. debra_bernstein@terc.edu

that both disciplinary and robotics learning was strengthened, determining where and how to support learning in both areas was challenging.

The current analysis, drawn from the first full year of Creative Robotics implementations in disciplinary middle school classrooms, highlights the different ways in which teachers adapted a flexible technology platform to support disciplinary learning goals. Specifically, we examine teachers' instructional and pedagogical strategies for reaching disciplinary goals while cultivating interest and learning about technology innovation.

**Theoretical Framework and Research Questions**

In recent years the U.S. educational system has fallen short in training technology innovators of the future (NRC 2010a, NSB 2010). We argue that if schools are to cultivate innovation, they must give students the experience of designing and creating a technological artifact, rather than relegating them to the role of technology consumers. Therefore, the Creative Robotics project charted a course for building technology fluency—the ability to manipulate technology creatively and for one's own use. In addition, those fluent with technology are able to reformulate knowledge and synthesize new information (NRC, 1999). Our approach to building fluency through integrative robotics projects is supported by our own (Bernstein, 2010; Hamner et al., 2008), and others' (Baker & O'Neil 2003; NRC, 1999) prior work.

To create access for all students and to tap unrecognized potential of those who are unlikely to select technology innovation experiences, Creative Robotics required integration within core middle school courses. This approach has the potential to serve more students well. Moreover, curricular integration, at least among the STEM disciplines, can improve learning (NRC, 2014). Opportunities to engineer robot models can promote deeper understanding and engagement with content (Gura, 2011; Gura & King, 2007), and by seeing creative modes of scientific exploration (as one might experience in robotics) students may develop better understanding in STEM generally (NSF, 2015).

Such an approach is not without challenge, however. Teachers need a diverse set of skills to deliver integrated education. "Apart from subject-specific content knowledge, the ability and confidence to teach across subjects will be critical for educators called upon to deliver integrated K-12 STEM education" (NRC, 2014, p. 7). For teachers to undertake curricular integration, studying how they go about it is essential, especially given that "…there is little research on how best to do so or on what factors make integration more likely to increase student learning, interest, retention, achievement, or other valued outcomes" (NRC, 2014, p. 2). In addition, there is a large body of research illustrating how teacher-curricular interactions lead to adaptations of new programs, as a result of teacher structuring, sequencing, and pacing, as well as the implementation of instructional strategies for monitoring and responding to student progress (Forbes & Davis, 2010; Brown, 2009). Thus, studying how teachers have shaped the Creative Robotics project in their classroom must be an essential part of the program's evaluation.

The Creative Robotics project has provided an opportunity to research how teachers integrate robotics into their disciplinary instruction, and to capture teachers' reflections about the value and challenge of their own integration efforts. The following exploratory research questions have guided aspects of our work that we present within this paper:

1. Does teacher practice reflect the goals and principles of Creative Robotics, which emphasizes the promotion of technological fluency and integration into disciplinary classrooms?
2. In what ways were teachers successful in using Arts & Bots to support exploration of robotics and to meet disciplinary instructional goals? What were the barriers?
3. What lessons can we draw from teachers' experience about the best ways to integrate creative robotics in middle school classroom?

**Evaluation Design and Methodology**

The researchers selected a descriptive case study approach (Yin, 2003) to explain teachers' decisions about robotics integration, including how teachers implemented Arts & Bots, and the classroom context in which these decisions took place. Our descriptive study of Creative Robotics teachers was designed to identify both common features and variations in robotics integration across different disciplines. This paper focuses specifically on how decisions about curricular integration influence implementation and the student experience.

This paper focuses on data from the first full year of the project. Fifteen middle school teachers (with 1-32 years of experience) from two school districts (one rural, one suburban) implemented Arts & Bots in health/physical education (2 teachers), English/language arts (3), art (4), science (3), social studies (2), and integrated STEM (1). Data were collected via the following instruments for each implementation of Arts & Bots:

- *Teacher artifacts*: lesson plans, rubrics, design worksheets, and student work.
- *Implementation calendar*: designed to record the types of classes and structure of the implementation.
- *Teacher implementation logs*: closed and open ended questions about lesson concepts/goals, student work during each phase (design, building, programming), and snapshots of teacher perceptions' of student engagement and learning.
- *Classroom observation/video guide:* prompts focus on teacher instructional moves, student-teacher interactions, and challenges/successes encountered (both pedagogical and technical).
- *Teacher final survey*: questions about teacher perceptions of professional development, how Arts & Bots supported teaching, and student technical and disciplinary learning.
- *Pre- and post-teacher efficacy surveys*: questions about teachers' ability to produce a desired outcome when implementing Arts & Bots.
- *Teacher interview (30 minutes):* designed to further capture teachers' instructional practice with Arts & Bots, including curricular integration and classroom context.

A coding rubric for text was designed to categorize curricular integration and instructional decision patterns as described in teacher interviews, and to document teacher response to ongoing challenges, unanticipated outcomes, and achievements.

Codes were applied using NVivo. For quantitative items, descriptive statistics were generated and associations were examined within each teacher's dataset.

## Findings

**Teachers' experiences implementing Arts & Bots.**[2] Across both school districts we identified 2 teachers who combined their classes and instructed a large group of 36 students in the fall and 40 students in the spring. The remaining 11 teachers implemented at one time point in the year. Two of these teachers used Arts & Bots in 3 of their class sections while the rest implemented with only one. Class size for these 11 teachers ranged from 9-26 students.

With two exceptions, Arts & Bots teaching sessions occurred during single class periods that were between 44-48 minutes long. Two teachers had block schedules, providing opportunities for 90-100 minutes of instruction, per class, daily. On average, students worked on their Arts & Bots projects for 11.75 class periods.[3]

Arts & Bots teachers were encouraged to choose a specific class topic that they thought would be well-suited to robotics integration. For many teachers, this was a bit of a risk, for if they discovered that the Arts & Bots curriculum did not enable them to cover the material well, they would need to reteach the subject matter in a more traditional manner. And there was little time in their schedules for this additional instruction. Therefore, we were eager to know the extent to which teachers felt Arts & Bots detracted from or enhanced their instruction.

Overall, teachers saw Arts & Bots as beneficial to their teaching, with 100% of this cohort providing a better than neutral rating (Figure 1). As one teacher described the experience "…creating something from scratch to move and demonstrate understanding…was a unique opportunity. I don't think I would have been able to do what I did with anything else but the robots." More specifically, teachers commented that Arts & Bots "…enhanced everybody's knowledge and awareness of our ancient Greece topics," pushed some students toward "deeper analysis" of symbolism in poems, and provided more time and opportunity to "…process the information of biomechanics."

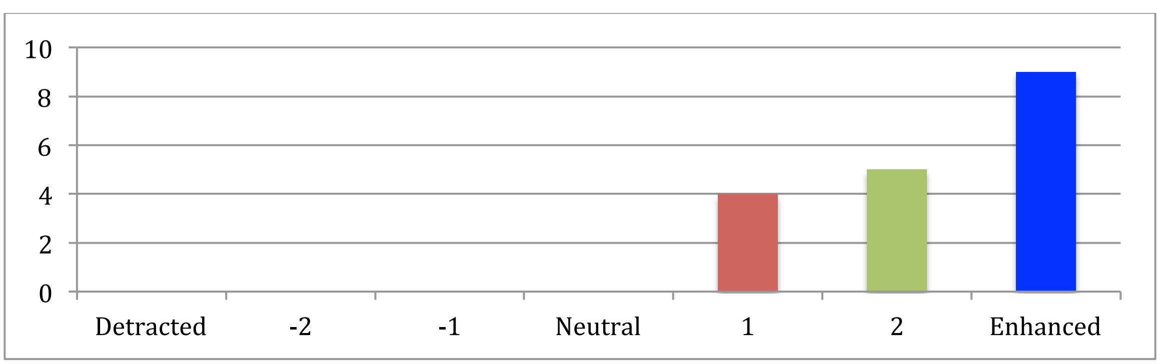


Figure 1. Teachers' ratings of Arts & Bots contributions to their teaching.

---

[2] We describe the structure of implementation of only 13 teachers, as 2 did not complete implementation calendars. The remaining sections of this paper include data from all 15 teachers.

[3] For this calculation, block classes were counted as two single periods.

We then probed further, asking about the benefit and drawbacks of Arts & Bots within specific aspects of the instructional experience. Using a scale where 1 indicated no support and 7 indicated great support, we asked the 15 teachers to rate the extent Arts & Bots supported them in using technology, facilitating group work, engaging students, and covering content. For each area, the average rating was greater than 6 (see Table 1), as only a few teachers gave ratings in the 3-5 range.

Table 1. Level of Support provided by Arts & Bots.

| **Teaching Area** | **Mean(SD)** |
|---|---|
| enabled me to use technology more fully in class | 6.57(.73) |
| provided me with an opportunity to do group work | 6.47(1.04) |
| offered a new way to engage my students in the topic we studied | 6.39(1.08) |
| extended or deepened my coverage of the topic we were studying | 6.11(1.27) |

Four teachers also noted additional ways that Arts & Bots supported their work. It enabled one person to advocate for strong technology usage in his district, another to include an opportunity for students to work across the curriculum, a third to see her own growth following several implementations, and a fourth to find a creative way for students to demonstrate their analysis of Shakespeare.

For the three teachers that provided lower ratings, one did not feel strongly that the curriculum supported group work in her classroom, but provided high ratings in other areas. Another teacher commented that her students got "…burnt out from the constant Arts & Bots lessons," and the third felt she needed help in integrating Arts & Bots into her curriculum as well as strategies to keep students invested in their projects.

Even though they were not specifically about the Creative Robotics instructional experience, contextual factors influenced the quality of teachers' implementations, especially in the more rural school district where materials management and extreme weather conditions were challenging. When plans for moving laptops and hardware from school to school fell apart, when teachers and students did not have sufficient time for or interest in gathering craft materials to support building, and when frequent and long stretches of school days were cancelled (for weather), implementations were not as rich or complete.

**Teachers' sense of efficacy.** While Arts & Bots provided opportunities, there were also demands associated with incorporating this new curriculum into middle school core subjects. Teachers had to be open to innovation and persistent when new lessons did not go smoothly. Such characteristics are indicative of a strong sense of efficacy (Jerard, 2007; Protheroe, 2008). Therefore, we gathered longitudinal data of teacher efficacy 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 (Enochs, Smith, and Huinker, 2000). These items are divided into two subscales: Personal Mathematics Teaching Efficacy (PMTE) and Mathematics Teaching Outcome Expectancy (MTOE). Previous research conducted by Enochs, Smith, and Huinker

(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's authors.

Fifteen teachers were included in this longitudinal efficacy analysis. All completed a baseline survey prior to initial professional development and their first Creative Robotics classroom implementation. Some teachers have remained with the project for several years and, thus, completed a post survey multiple times. For consistency, we used post-scores from the surveys completed after each teacher's final implementation. Appropriate recoding was completed on negatively scored items to create composite scores for each subscale prior to conducting a test of pre to post change.

Analyses for the *Personal Mathematics Teacher Efficacy* subscale showed a significant effect of time on pre to post scores, ($t(14) = 2.234$, $p < 042.$). For *Mathematics Teacher Outcomes Expectancy* subscale there was no significant effect of time on scores.

Given our small number of teachers and the exploratory nature of our Creative Robotics 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, the supports 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.

Data from the current project year (still in process) will enable us to learn more about the successes and challenges that teachers experience when integrating engineering and computational thinking activities through Arts & Bots, and whether, over time, this has some influence on their sense of efficacy.

**Teacher implementation: A spectrum of disciplinary focus.** In addition to examining data for the corpus of Creative Robotics teachers as a whole, our analysis also explored the different ways in which these teachers integrated robotics into their disciplines. While all 15 teachers ran worked on Arts & Bots projects with their students, their implementations represent a range of curricular integration. Consistent with the Creative Robotics goals, teachers embraced and worked to fulfill technology-based objectives (e.g., exposing students to technology, increasing familiarity with robotics and programming). However, the teachers varied in the extent to which they connected Arts & Bots with disciplinary learning goals.

Our analysis suggests a spectrum of disciplinary integration. In some cases, Arts & Bots was fully integrated into the discipline (although this was accomplished in a number of different ways). In other cases, teachers used Arts & Bots to provide students with a wider exposure to their discipline, but did not articulate specific disciplinary learning goals. Finally, in some cases there was no clear connection between Arts & Bots and core disciplinary content.

***Integrating disciplinary content and robotics.*** Four Arts & Bots implementations (one in health, three in English/language arts; all from the suburban school district) integrated robotics and disciplinary content. We considered a project to be integrated into the discipline when:

- the project's topic could be linked to a disciplinary 'big idea',
- the project was designed to support the development of key concepts underpinning that idea, and
- classroom activities, design materials (e.g., student design notebooks), and grading rubrics all supported and reinforced learning goals in the integrated discipline.

*Biomechanics***.** Two teachers (health/physical education) worked together to design and implement an Arts & Bots project on biomechanics ("how muscles, joints, and bones work together to make movement"). Similar to the way that modeling activities are often used in science classrooms to facilitate students' understanding of complex biological systems, these teachers used robotics to enable student exploration of the structures and functions of muscles and joints (Hmelo-Silver et al., 2000; Hmelo-Silver & Pfeffer, 2004).

This implementation was designed around the specific learning goal of deepening students' understanding of antagonistic muscle pairs (i.e., the idea that muscles work in flexor/extensor pairs or groups of pairs to control a joint). Students used Arts & Bots materials to develop robotic models of elbows, knees, or shoulders (Figure 2) that accurately represented antagonistic muscle movement, and in this way were functionally similar to muscles.

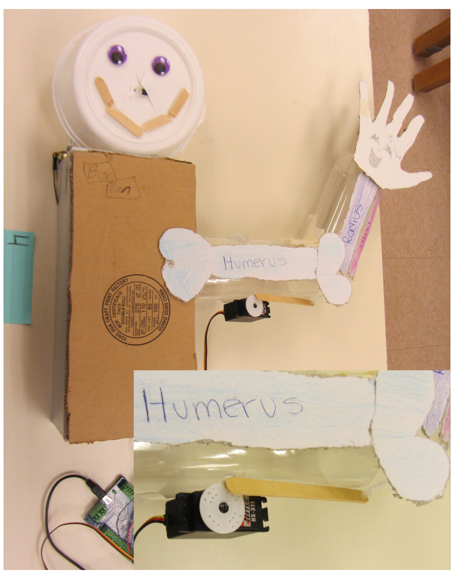


Figure 2. Student robot from a 7th grade health lesson on biomechanics.

The disciplinary learning goal was reinforced in a number of ways. Students began the design process by conducting research on their chosen joint and drawing a robot schematic that included labels for the relevant muscles and bones, a list of materials they would use to build their robot (including technology), and an explanation of how the muscles would cause movement. Only sketches that included plausible robot designs (i.e., the technology described in the sketch could actually produce the anticipated movement), and that demonstrated an understanding of joint structure and function would be approved for building and programming. The grading rubric also reinforced project learning goals by awarding points for inclusion of technology, correct labels (of muscles, bones, and tendons), and motion that correctly represented biomechanics principles.

A review of classroom video shows that teachers reinforced both design and disciplinary learning goals throughout the implementation. Student-teacher conversations often included discussions about anatomy and body structures, and emphasized the project goal of representing biomechanically-correct movement. The following comments offered by the health/physical education teacher to students provide examples of this:

> This shoulder muscle is called your deltoid, and here's your pectoral… I'm looking for which muscle is the flexor and which one is the extensor? So, which muscle of these two is closing your shoulder joint?
>
> I want you to show me the muscles working. So when you pop a servo [motor] right in there, that doesn't accurately represent the movement because the muscle up here actually connects down like that. The muscle pulls it up this way, so if you just pop a servo [motor] in there that's not the right motion.
>
> I don't want the servo [motor] to move the joint, I want the muscles to move the joint. So you need to figure out how the servos are going to pull the muscles.

*Literary Symbolism.* Three English/language arts teachers implemented "Robot Theater," an Arts & Bots project designed by the school's gifted support coordinator to enhance student understanding of literary symbolism. Two teachers implemented Robot Theater during or immediately after a unit on *Romeo and Juliet*, and the third implemented Robot Theater during a poetry unit.

Through Robot Theater implementations, students conduct a close analysis of literary text, enabling them to interpret literary symbols and design a robotic scene where the use of lights, motors, and sensors communicate the mood and meaning of the text. For instance, some students were able to demonstrate symbolic actions and elements in *Romeo and Juliet* using different color lights (e.g., green for poison, red to symbolize death) while other students used motion. One teacher explained how a group of her students were "able to plan out how to visually represent a battle of wits between Mercutio in terms of raising each character higher as they 'gained a point' in creatively making fun of one another… Some of my students had a lot of success in [interpreting] Shakespeare's use of creative insults and plays on words."

Disciplinary learning goals in Robot Theater are reinforced through the use of grading rubrics that emphasized student understanding of the text (monologue, soliloquy, or poem) and awarded points based upon the quality of the symbolism. Student design notebooks also emphasized close reading of text by scaffolding students to extract symbols from literary passages and develop representative elements on their robot.

One teacher who implemented Robot Theater during *Romeo & Juliet* described the design activities as providing a way for students to "get in [the text] and move around and understand how they could represent something visually simulating, to provide some sort of visual symbolism." Another teacher reflected that the activities provided a way for students to demonstrate their understanding, "like by what they're choosing to put in it, and what they're choosing to have lights on…. So they are thinking about the symbolism, but it's like more of an outward expression, like this is helping me express what I get out of it."

*Summary***.** The four projects described in the 'integration' category all connected disciplinary content and robot design activities. Although the content domains were different, one common element of all four projects was that they leveraged robotic design to make abstract concepts more concrete. As the teachers focusing on biomechanics explained, their goal was to have students, "actually replicate the motion, and present a diagram or an explanation of what is actually happening, as opposed to thinking about it in the abstract." The language arts teachers described Robot Theater as providing students with an opportunity for 'outward expression' of literary symbolism. Indeed, the flexibility afforded by a robotics design environment seems well-suited to concrete expressions of concepts in a range of disciplines.

***Exposing students to disciplinary content using robotics.*** Five implementations (two in social studies, one in art, one in science, and one in integrated STEM; from both school districts) used Arts & Bots to broaden their students' exposure to disciplinary content. These exposure projects connected robotics to the discipline in a general sense, but did not identify a specific disciplinary learning goal. For example, one teacher explained her approach to using Arts & Bots in her social studies class,

> I started thinking, there are so many other cool structures outside of a particular culture…And then I start thinking to myself,...[Students study] the fall of the Roman Empire through the early explorers, but we stop at [that point]. So in 8th grade, we're learning about places like the Taj Mahal, and the Hagia Sofia, and the temples at Lalibela. And as we were studying those this year…I was thinking, wow, these would be cool structures to build. And so that's what I did. I kind of compiled a list. I started with the seven wonders of the ancient world…. And then I also thought I would be remiss if I didn't add some of the natural wonders of the world, like the Grand Canyon…. So instead of narrowing the topic down, I broadened it. …I just thought these topics were life-learning topics.... I mean, those are things that I would feel bad if they never were exposed to. …I don't know where else they would be exposed to them. *[Arts & Bots teacher, social studies]*

For another social studies project, students created robots that represented 'captains of industry' during the Industrial Revolution, for example creating a man from the Transcontinental Railroad and train engines. This social studies teacher believed the project "caused [students] to focus more" on specific events and/or inventions because students had to conduct research and present their projects to the class. When discussing curricular integration, this teacher focused on learning behaviors such as being able to concentrate on specific tasks and did not comment on academic standards.

Similarly, another STEM teacher had her students “research a historical scientific figure, either a scientist or a theory that they were interested in, and they had to do a Powerpoint to go along with their robot.” For this teacher, it was important for students to explore and research a topic or person they were curious about. One student created a robotic tree dropping an apple on Isaac Newton’s head to exhibit the law of gravity. Teacher expectations were about exposure and giving students opportunities to interact with Arts & Bots materials. As one teacher stated, “I didn’t give them a lot of structure this time as far as an actual class topic, just because I wanted them to get a feel for the tools and the resources and all those kinds of things.”

While this group of teachers generally focused on disciplinary exposure (as opposed to integration), some did have larger disciplinary learning goals for their students. For example, one teacher wanted students to understand how scientists’ discoveries changed people’s lives, and to increase the students’ appreciation of certain aspects of life that they may take for granted (i.e., the invention of soap). For another teacher, it was important students took time to “stop and think and analyze and put down on paper what [they] are thinking [and what they] are doing.” Although these two teachers did not explicitly talk about curricular integration, it became visible they wanted their students to take their projects a step further and justify their thinking.

Teachers who structured their Arts & Bots curricula around exposure also commented upon the non-cognitive qualities they felt were important during implementation, such as curiosity, self-discipline, persistence, conscientiousness, perseverance, collaboration, following directions, organization, and focus. According to Tough (2012) these non-cognitive skills are imperative for a student’s future success. One teacher described how students were persistent when making their robots,

> [Building robots] made them really think. Because normally they’re like, oh, this isn’t working. And they’re like, hey, [teacher], fix this for me. Or [teacher], tell me how to do this. And I just told them that part of that project was not only researching, but figuring it out, problem solving, breaking it down on their own…. They didn’t ask me. Sometimes they would ask each other, and then they would break it down, but it made them…break it down and figure out that it was [a problem in their] programming. *[Arts & Bots teacher, science]*

More importantly, Arts & Bots provided an opportunity for students to fail and to learn from their lack of success (Wagner & Compton, 2012). One teacher explained how the students worked together and would learn from their mistakes:

> They worked together and came up with their ideas, and they kind of fed off of each other. What one student was weak in, the other kids picked up, and they picked up the slack and they all just worked really well together. When a piece would fall off or something would break, they would all pitch in and work together to get it fixed. They were really good about troubleshooting. If they couldn’t get something to turn in just the way they wanted it to, then they all

> worked together to get that done. And that's one of the things that all the students did. *[Arts & Bots teacher, art]*

As these examples suggest, some teachers believed that exposure to robotics provided a number of non-disciplinary learning opportunities for their students. Instead of focusing on a specific topic or concept, these teachers emphasized learning behaviors more broadly. Perhaps the reason for teaching non-cognitive skills was the belief that "school achievement is determined by a variety of non-cognitive skills such as the ability to follow directions, work in groups, pay attention in class, and organize materials" (Jacob, 2002, p. 8). Their approach underscores their sense that Arts & Bots was an opportunity for students to gain content exposure and a range of other skills in a new way.

***No clear connections to core disciplinary goals or content.*** While the majority of the teachers found ways to make connections to the subject matter of their discipline, a small group of teachers did not. Instead, they focused on using Creative Robotics projects to increase student comfort and familiarity with technology. This group of teachers designed assignments that prioritized creativity. For instance, one teacher described her expectations for student robots as follows:

> They had to have a moving part. They had to use the LED's [lights] on it. And it had to have a reaction to cause all of that, and there had to be a change in the LED. And that was the assignment. On that end, they could do whatever they wanted with the materials. So I gave them free range on that, which allowed for a lot more creativity. We didn't talk so much. I just let them go. *[Arts & Bots teacher, art]*

Other teachers drew links between course content and robotics activities, but these links were not as goal-directed as the patterns described above. One science teacher asked students to build animal-themed robots. An art teacher suggested connections between robots and sculpture, but also emphasized creative freedom:

> [Through robotics] I wanted them to get a feel for... building a sculpture. We did talk a lot about different types of sculptures and things like that. So I did bring that in for a class topic. And then they assembled their projects, and then added the electrical components to them. And I had several of them that told me that they really enjoyed having that complete freedom to just make whatever kind of robot that they wanted to make. *[Arts & Bots teacher, art]*

The reasons for this are not entirely clear, and data are being collected to understand both barriers and teacher decision-making more fully. There is some indication that a few of these teachers needed more support in designing projects that explicitly linked disciplinary topics with robotics. For instance, in response to a question on the final survey about future needs, one said she would need help "writing lessons plans to use in the classroom with Arts & Bots," and another described how she would be helped "…by actually getting integrating strategies" that went beyond general tips that were offered. Overall, there was a sense that this group felt that emphasizing exploration and providing opportunities to practice craftsmanship and problem-solving skills were sufficiently worthy of the time allotted for Arts & Bots. For them, curricular integration was not the priority.

**Discussion**

Our analysis of teachers' implementation of Arts & Bots yielded different instructional and pedagogical strategies for achieving disciplinary goals while facilitating student interest and learning about technology. Teachers in our study integrated robotics into core disciplinary classes in a way that supported disciplinary goals; increased exposure to ideas or curricular material that students would not otherwise have an opportunity to engage with in-depth; and exposed students to creative technology with minimal integration into disciplinary content.

The significance of this work is underscored by the recent NAE/NRC report, *STEM Integration in K-12 Education* (2014), which encourages researchers to document the scaffolds and instructional designs used in integrated interventions, as well as the support provided to achieve those interventions. In line with this charge, our work underscores the importance of integrated robotics curricula that considers both the needs of the discipline and the affordances of the robotic technology. Most of the disciplinary teachers in this study took an approach to integration that suited their instructional and pedagogical needs. Data collected during subsequent project years will allow us add depth and breadth to the implementation summaries. Future analysis will explore the types of support required to enable successful integration and implementation, and the ways in which teachers approach the challenges associated with technology integration. We believe these findings will be useful as the field moves further towards the goal of integrated education.

**References**

Baker, E. L., & O'Neil, H.F. (2003). Technological fluency: Needed skills for the future. In H.F. O'Neil, & R. Perez (Eds.), *Technology applications in education: A learning view*. Mahwah, NJ: LEA.

Benitti, F. (2012). Exploring the educational potential of robotics in schools: A systematic review. *Computers & Education, 58,* 978-988.

Bernstein, D.L. (2010). Developing technological fluency through creative robotics (Doctoral dissertation). Retrieved from ProQuest Dissertations and Theses. (Publication number AAT 3435373).

Brown, M. (2009). The teacher-tool relationship: Theorizing the design and use of curriculum materials. In J. Remillard, G. Lloyd, & B. Herbel-Eisenmann (Eds.), *Mathematics teachers at work: Connecting curriculum materials and classroom instruction* (pp. 17–36). New York: Routledge.

Cross, J., Bartley, C., Hamner, E., & Nourbakhsh, I. (2013). A Visual Robot-Programming Environment for Multidisciplinary Education. *IEEE International Conference on Robotics and Automation (ICRA),* Karlsruhe, Germany.

Enochs, L., Smith, P., Huinker, D. (2000). Establishing Factorial Validity of the Mathematics Teaching Efficacy Beliefs Instrument. *School Science and Mathematics,* 100(4), 194-202.

Forbes, C. & Davis, E. (2010). Curriculum Design for Inquiry: Preservice Elementary Teachers' Mobilization and Adaptation of Science Curriculum Materials. *Journal of Research in Science Teaching,* 47(7), 820-839.

Gura, M. (2011). Getting Started with Lego Robotics: A Guide for K-12 Educators. VA: ISTE.

Gura, M. & King, K. Ed. (2007). Classroom Robotics: Case Stories of 21st Century Instruction for Millennial Students. NC: IAP.

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

Hamner, E., & Cross, J., (2013). Arts & Bots: Techniques for distributing a STEAM robotics program through K-12 classrooms. In *Proceedings of the 2013 IEEE Integrated STEM Education Conference (ISEC).*

Hamner, E., Lauwers, T., Bernstein, D., Nourbakhsh, I., & DiSalvo, C. (2008). Robot Diaries: Broadening participation in the computer science pipeline through social technical exploration. In *Proceedings of the AAAI Symposium on Using AI to Motivate Greater Participation in Computer Science.*

Hmelo, C., Holton, D., Kolodner, J. L. (2000). Designing to learn about complex systems. *Journal of Learning Sciences,* 9, 247–298.

Hmelo-Silver, C. and Pfeffer, M. (2004). Comparing expert and novice understanding of a complex system from the perspective of structure, behaviors, and functions. *Cognitive Science* 1, 127-138.

Jacob, B. A. (2002). Where the boys aren't: Non-cognitive skills, returns to school and the gender gap in higher education. *Economics of Education review*, *21*(6), 589-598.

Jerald, C. D. (2007). *Believing and achieving (Issue Brief).* Washington, DC: Center for Comprehensive School Reform and Improvement.

National Academy of Engineering and National Research Council. (2014). *STEM Integration in K-12 Education: Status, Prospects, and an Agenda for Research*. Washington, DC: The National Academies Press.

National Research Council. (NRC, 1999). *Being fluent with information technology.* Washington, DC: The National Academies Press.

National Research Council. (NRC, 2010a). *Rising above the gathering storm, revisited: Rapidly approaching category 5.* Washington, DC: The National Academies Press.

National Science Board. (NSB, 2010*). Preparing the Next Generation of STEM Innovators: Identifying and Developing our Nation's Human Capital*. Arlington, VA: National Science Foundation.

Protheroe, N. (2008). Teacher efficacy: What is it and does it matter? *Principal,* Retrieved on February 5, 2014 at https://www.naesp.org/resources/1/Principal/2008/M-Jp42.pdf.

Tough, P. (2012). *How children succeed: Grit, curiosity, and the hidden power of character*. Boston, MA: Houghton Mifflin Harcourt.

Wagner, T., & Compton, R. A. (2012). *Creating innovators: The making of young people who will change the world*. New York: Scribner.

Yin, R. (2003). *Case study research: Design and methods*. Thousand Oaks, CA: Sage Publications.