Chapter 8

Programming Robots in Kindergarten to Express Identity:

An Ethnographic Analysis

Marina Umaschi Bers
Tufts University, USA

Alyssa B. Ettinger
Tufts University, USA

ABSTRACT

This chapter presents a research program that uses robotics as a powerful tool to engage Kindergarten children in developing computational thinking and learning about the engineering design process. Using an ethnographic analysis of an experience in a Kindergarten classroom at the Jewish Community Day School (JCDS), a pluralistic school in Watertown, MA, in which children worked with robotics as a way to explore issues of identity, the chapter highlights both developmental and technological considerations that need to be addressed when engaging young children with robotic activities. This project used an innovative hybrid tangible programming system composed of interlocking wooden blocks, called CHERP, specifically designed to meet the developmental needs of young children. While many robotic programs highlight building aspects and their relationship to engineering education, the approach presented in this chapter complements this by focusing on programming by teaching powerful ideas from computer science at a very early age.

INTRODUCTION

Typically, "robotics" brings to mind metallic human-like contraptions wired with complex electronics. However, this chapter describes an experience in which simple Lego-based robotic cars were programmed by Kindergarten children with smart wooden blocks using CHERP (Creative Hybrid Environment for Robotic Programming), a developmentally appropriate tangible language (Horn, Crouser & Bers, 2011). This work was inspired by the realization that in the early grades, children learn very little about engineering and technology. Just as it is important to begin science instruction in the early years by building on children's curiosity about the natural world,

DOI: 10.4018/978-1-4666-0182-6.ch008

it is as important to begin engineering instruction and the development of technological literacy by building on children's natural inclination to design and build things, and to take things apart to see how they work (Bers, 2008; Petroski, 2003). Robotics is a wonderful platform that taps into what is unique to today's human-made world: the fusion of electronics with mechanical structures.

With the growing popularity of robotics, the use of educational robotic kits and programming languages for controlling the robot's behaviors is becoming widespread in high schools, middle and elementary schools (Rogers, Wendell & Foster, 2010). In order to bring robots to "life" children must create computer programs—digital artifacts that allow robots to move, blink, sing, and respond to their environment. Previous research has shown that children as young as four years old can understand the basic concepts of computer programming and can build and program simple robotics projects (Bers, 2008; Cejka, Rogers, & Portsmore, 2006; Bers et al, 2006; Bers & Horn, 2010; Kazakoff & Bers, 2010; Bers, 2010a). However, young children need to work with interfaces that are developmentally appropriate. The robotics-based programming language we used, called CHERP, is such a tool and was developed by Bers and her DevTech research team at Tufts University (Horn et al., 2011). Rather than writing computer programs with a keyboard or mouse, the CHERP system allows children to instead *construct* physical computer programs by connecting interlocking wooden blocks. CHERP is described in the following section.

This chapter takes an ethnographic approach to analyze and describe the learning experience of 23 Kindergarten students who participated in a month long robotics curriculum called TangibleK, developed by the DevTech research group at Tufts University with funding from the National Science Foundation. The TangibleK curriculum, which utilizes CHERP to teach robotics and computer programming concepts to Kindergarten students, was adapted and extended to explore issues of identity at the pluralistic Jewish Community Day School (JCDS) in Watertown, MA. While the TangibleK curriculum encourages cognitive development in such areas as logical and sequential thinking (Kazakoff & Bers, 2010), the overarching project goal at JCDS was not only to engage children in learning about robotics, but also to provide them with robotics as a different medium, to express their explorations of identity in a creative way.

We collaborated with JCDS Kindergarten teachers to incorporate the TangibleK curriculum into the class' end-of-year project that encouraged the students' reflection of their accomplishments during the school year and their developing sense of self. This culminating project was called *Mi Ani* ("Who am I," in Hebrew). The extension to the TangibleK curriculum for the *Mi Ani* project focused on the creation of robotic artifacts and programmed behaviors to express the kindergartners' individual Jewish identities. Because the medium of robotics allows the display of actions, as opposed to static facts, children chose to create robots enacting behaviors that are related to their different ways of being Jewish. For example, one student programmed his robot to spin to represent lighting the Hanukkah menorah, while another programmed hers to roll back and forth, mimicking rolling out dough for Passover matzah. The robots created by the children represented a sense of dynamic identity, "chosen" by the children. The dynamic process that enhanced the conceptualization of identity involved engaging children in deciding how to make their robots, what aspects of their Jewish identities to convey through them, and how to program them to respond to certain events in the Jewish calendar (Libman, 2011; Bers & Urrea, 2000).

CONTEXT OF STUDY

Setting

At JCDS, 23 children in the *Gan Nitzan (Kindergarten)* class participated in the Mi Ani project using the TangibleK robotics curriculum developed by the DevTech team at Tufts University (Bers, 2010b). The philosophy of the school is one that supports progressive, child-centered learning styles, which provided a welcoming environment for the TangibleK curriculum. The school is philosophically committed to intentional pluralism, meaning that it actively embraces children and families with a wide range of Jewish expression, practice, and belief. Pluralism at the school extends beyond variations of Jewish religious affiliation. For example, the school's curriculum embraces differentiated instruction, celebrating the diversity of learners represented within the school's community.

Gan Nitzan is a combination of the Hebrew words *gan*, meaning 'Kindergarten' or 'preschool' and *nitzan*, meaning 'flower bud'. The Kindergarten has full days of school Monday through Thursday (8:00 am to 3:30 am) and a shorter day on Fridays (ending at 2:00 pm) in anticipation of *Shabbat*, the Jewish Sabbath. The Kindergarteners have two main teachers, and often an assistant teacher as well, to achieve a low student-teacher ratio. The *Gan Nitzan* classroom balances a developmentally sensitive academic structure with an emphasis on supporting the Kindergarteners' creativity and individual learning styles. The main curriculum integrates academic studies with Judaic studies, and fosters respect for multiple perspectives while promoting curiosity and a passion for learning. The main curriculum comprises English literacy studies, integrated Hebrew lessons, *Humash* (Bible) study, math, science, and social studies. Specialists also teach several additional subjects: physical education, art, music, Israeli dancing, and movement (a class that promotes body awareness). Of note, each grade at the JCDS has an overarching "central subject" that shapes all main areas of their curriculum. The Kindergarten's central subject is "Cycles", which is explored across multiple domains, such as the study of the cyclical Jewish holidays, the life cycle of plants and butterflies, and recognition of patterns in stories. *Gan Nitzan's* final project, *Mi Ani*, highlights the cyclical nature of time while celebrating the self-reflection of the Kindergarteners' experiences throughout the school year.

The *Mi Ani* project lasted for a period of one month and culminated in a final open house for family and friends where children presented their robots. One of the two main classroom teachers, who was trained in the technology by the DevTech Team, and two DevTech researchers, were in charge of classroom instruction. The curriculum that formed the foundation of the *Mi Ani* project was implemented in two stages. First, children were introduced to the robotic technology and the CHERP programming language by engaging with the TangibleK curriculum. This curriculum taught children computer programming and engineering concepts and provided a structured way for children to put those concepts to use by engaging in small-scale activities and challenges. Once children mastered the basics of programming and building robots, the second part of the curriculum focused more specifically on the *Mi Ani* project. Together with their teachers, children reflected on their experiences and learning during the year, coming up with a timeline consisting of the different activities, during each academic month, that were meaningful to them (see Figure 1).

Each child chose three moments in the year as "stations" at which his or her robot would stop and perform a program to represent the child at that given moment. For example, one child programmed his robot to stop along the timeline at November, spinning to represent eating turkey on Thanksgiving, while another programmed her robot to sing at December to show singing Hanukkah songs. The children decorated the robots to represent their self-identities, using art materials

Figure 1. A section of the timeline of the Kindergarten year

to depict them, their interests, and their characteristics. For example, one child decorated her robot with drawings of all her favorite sports, while another molded a clay image of herself that she attached to the top of her robot. Finally, children combined their three robot programs from individual moments in the year into one comprehensive program, which represented their journey throughout the year. Each child programmed his or her robot to travel alongside the timeline, demonstrating the children's own understanding of significant moments of their experience throughout the year.

CHERP in the Classroom

The teachers created an environment that emphasized an engineering mindset, with a focus on teaching the Engineering Design Process and with the impetus to engage Kindergarteners to consciously take on the identity of engineers. Students were immersed in a community of engineers that shared a set of core values, knowledge, skills, and identities. At the introduction of the TangibleK curriculum, the Kindergarteners were explicitly introduced to the Engineer Design Process, which was presented to the class as a visual web that cycled through the five steps: *ask, imagine, plan, create, improve.* The teachers discussed and provided examples for each step, emphasizing that the students would become engineers when they engaged in the process of designing and programming their own robots.

After about one week of lessons on sturdy building with Lego blocks and understanding what a robot is, the children were actively taught the robotics technology. The TangibleK program uses CHERP in combination with different robotic kits. For this project we used the Lego MINDSTORMS© RCX brick, an embedded micro-computer or the "robot brain". The programs children created with the CHERP tangible blocks were downloaded to the Lego RCX brick using infrared. The CHERP programming language draws on work from the field of human computer interaction (HCI) on tangible interfaces that shows that we can overcome the inherent limitations of writing computer programs with a keyboard or mouse, by offering tangible systems (Blikstein, Buechley, Horn & Raffle, 2010). Tangible languages, instead of relying on pictures and words on a computer screen, use physical objects to represent the various aspects of computer programming. Users arrange and connect these physical elements to construct programs. Tangible languages exploit the physical properties of objects such as size, shape, and materials to express and enforce syntax. This is crucial when working with Kindergarten age children who might not have developed the motor skills to work with a mouse interface or who might need physical objects to manipulate in order to understand abstract concepts (Horn et al, 2011; Bers & Horn, 2010).

With the CHERP system, young children can transition back and forth between using interlocking tangible wooden blocks, or onscreen programs using the same icons that represent actions for their robots to perform (see Figure 2). This hybrid approach allows children to work with multiple representations (Horn et al, 2011).

CHERP uses a collection of image processing techniques to convert physical programs into digital instructions. A standard webcam connected to a desktop or laptop computer takes a picture of the program. A compiler converts the picture into digital code that gets downloaded to the robot in a few seconds.

Children worked in eleven pairs, while one child worked alone. This set-up fostered the potential for collaboration and social development along with cognitive gains. Each group shared an RCX brick to build a car, onto which they connected two Lego motors and wheels and a "leg" in the front to keep the base upright. Each pair also had a mini laptop station set up with the CHERP software, a webcam to scan in the wooden block, and a Lego tower to upload the programs to the RCX brick. Large bins of Legos and CHERP wooden blocks were available on the rug to be shared by all of the students.

Figure 2. The CHERP language developed at Tufts University. Children construct programs for their robots using interlocking wooden blocks.

TangibleK Curriculum: Introduction to Programming

The overarching goal of the TangibleK curriculum is to introduce young children to computational thinking. Computational thinking is a type of analytical thinking that shares many similarities with mathematical thinking (e.g., problem solving), engineering thinking (designing and evaluating processes), and scientific thinking (systematic analysis). The foundation for computational thinking is abstraction – abstracting concepts from cases and evaluating and selecting the "right" abstraction. It relies on selection of inputs (manipulation of variables and computational instructions), observation of outputs (outcome data), and decomposition of what happens in between. Computational thinking is about the ability to abstract from computational instructions (programming languages) to computational behaviors, to identify potential "bugs" and places for errors, to decide what details among the input-computation-output algorithm to highlight and retain and what details to discard (Wing, 2006).

The term computational thinking grew out of the pioneer work of Seymour Papert and colleagues on design-based constructionist programming environments, to refer to ways to algorithmically solve problems and to the acquisition of technological fluency (Papert, 1980; Papert, 1993). Previous work on young elementary school-aged children and computational thinking can be found in the research literature on constructionist programming environments (Repenning, Webb, & Ioannidou, 2010; Resnick, Maloney, Monroy-Hernandez, Rusk, Eastmond, Brennan, et al., 2009, 2009). Wing (2006) describes computational thinking as a fundamental skill for everyone, not just for computer scientists.

In order to engage children in computational thinking, the TangibleK curriculum focuses on the following powerful ideas: robotics, engineering design process, sequencing and control flow, loops and parameters, sensors and branches. See Table 1 for descriptions of these.

The TangibleK curriculum is designed for a minimum of 20 hours of classroom work, divided into the following structured sessions based on the six powerful ideas identified above:

1. Sturdy building (the engineering design process);
2. What is a robot? (robots have special parts to follow instruction);
3. Hokey-Pokey: sequence of commands (the sequence or order of commands matters);
4. Again & Again Until I Say When (loops and number parameters);
5. Through the tunnel (sensors and loops); and
6. The robot decides (sensors and branches).

In the first phase of the curriculum, the teachers taught the CHERP system one lesson at a time, with directed challenges following the teaching of each new type of block representing an action. One of the first lessons challenged the children to make their robots dance the "Hokey Pokey". This required mastery of the CHERP syntax and the sequential nature of computer programming. For example, the "Hokey Pokey" program used the following sequence of commands:

BEGIN/FORWARD/BACKWARD/FORWARD/SHAKE/SPIN/END.

The robotics terms were taught by comparing electronic parts to human body parts, such as the "ear" of the robot that receives the signals of the program from the computer tower. During one morning meeting, a teacher led a very successful game where a student acted out his own program and the class had to guess what the program blocks were. Bodrova and Leong (2007) emphasize play as the time when most learning takes place, in particular during cooperative dramatic play, which involves taking on different roles. Activities in

Table 1. The six powerful ideas of the TangibleK program

Powerful idea	**Definition**	**Activity**	**Discipline connections**
Robotics	The engineering discipline that focuses on the creation and programming of robots, machines that can follow instructions and move on their own to perform tasks.	*What Is a Robot?* After an introduction to robotics by looking at different robots and talking about the functions they serve, children build their own robotic vehicles and explore their parts and the instructions they can use to program them.	• Engineering • Computer Science
Engineering design process	A process used to develop products to solve a need or problem. It has several iterative steps: identifying a need or defining the problem, doing research, analyzing possible solutions, developing the product, communicating and presenting the product.	*Sturdy building:* Children build a non-robotic vehicle to take small toy people from home to school. The vehicle needs to be sturdy as well as perform its intended functions.	• Engineering • Computer science
Sequencing / control flow	A sequence of instructions can be described in a program and acted out in order by a robot. Each block has a specific meaning. The order of the blocks is important.	*The Hokey-Pokey:* Choose the appropriate commands and put them in order to program a robot to dance the Hokey-Pokey.	• Creative storytelling • Organization of ideas • Mathematical proofs • Procedural thinking
Loops and Parameters	A sequence of instructions can be modified to occur over and over again. Control flow commands can be qualified with additional information. For example, loops can be modified to repeat forever or a concrete number of times.	*Again and Again until I Say When:* Students use a pair of loop blocks ("repeat" / "end repeat") to make the robot go forward again and again, infinitely and then just the right number of times to arrive at a fixed location.	• Cyclical events in nature • Scheduling • Timing and control • Feedback loops • Number sense
Sensors	A robot can use sensors, akin to human sense organs, to gather information from its environment. Sensor information can be used to control when the robot follows given commands.	*Through the Tunnel:* Children use light sensors and commands to program a robot to turn its lights on when its surroundings are dark and vice versa.	• Scientific observations • Cause and effect • Sensors (both human-made and natural)
Branches	At a branch in the program, a robot can follow one set of commands or another depending on the state of a given condition.	*The Robot Decides:* Students program their robot to travel to one of two destinations based on light or touch sensor information.	• Cause and effect • Sensors (both human-made and natural)

which the children and robots took on each other's roles likely allowed the Kindergarteners to better learn how the robots work through a sort of dramatic play.

ETHNOGRAPHIC ANALYSIS OF ROBOTICS EXPERIENCE

Our methodology for this ethnographic study involved the full immersion of the ethnographer into the *Gan Nitzan* classroom during the month of

Figure 3. The CHERP program for performing the "Hokey Pokey" dance, as it would appear on the graphical computer interface

the TangibleK curriculum. The ethnographer was introduced to the class as an assisting member of the DevTech research team, and was familiar with the TangibleK technology and software so that she could actively participate in the curriculum. She worked with the students throughout the curriculum and conducted face-to-face interviews with the children as they developed their robotics skills and projects. Observation notes were compiled each day along with frequent audiovisual documentation, and the ethnographer helped administer the post-curriculum assessments of the students at the end of the curriculum. During robotics lessons, the ethnographer was free to navigate the classroom to observe, interview, and offer help to those students who needed it. The role of the ethnographer as an active participant in the classroom allowed her to form positive relationships with the children and to experience each phase of the curriculum from their perspectives.

Programming Challenges and Learning to Fail

As the children were introduced to complex blocks, the programming challenges became more difficult and children faced confusion and frustration as they began to deal with many more failures than successes. For example, one of the later lessons exposed the children to light sensors and light bulbs that can connect to the robot brain. One of the head JCDS teachers began the lesson asking the children to think about how we would tell whether it is day (light) or night (dark), highlighting the comparison between the robots' light sensors and our eyes. This attribution of human characteristics to the robot parts again allowed the children to easily grasp the concept of the light sensors. Utilizing this new material and building upon the repeat loops from the previous lesson, the challenge of the day was to create a program that took their robot down a straight "street" and through a dark tunnel, turning on its light when it was inside the tunnel, and then back off when it reached the other side. This challenge was certainly more complex than previous ones because it necessitated repeat loops with light sensors as the parameter, a novel combination that was not explicitly modeled for the children.

Perhaps because of the steady pace at which the curriculum was moving, most children were not yet comfortable enough with the repeat loops to manipulate them for such an abstract challenge. Without being able to work from a model, many children began the challenge with little direction and were easily distracted by their classmates. Subsequent prompting from the teachers did provide some scaffolding for a few students to come close to solving the challenge, but for the first time the majority of students were not successful. Many children were still unsure of how exactly to use the repeat loops, especially with qualitative rather than quantitative parameters.

As a result, the class did not necessarily master the conceptual content, but the lesson was crucial in establishing the mindset that initial failure is acceptable. The students were always encouraged to continuously test out their robot and modify their program, following the Engineer Design Process, but this was one of the first challenges in which there were multiple solutions and many more opportunities for trial and error. A compounding difficulty was that the light sensors themselves proved finicky and resulted in a false negative feedback for most of the students when they tested their robot's performance of the programs.

During the last few minutes of the robotics period, the teachers led "Technology Circles" for the students to share their programs and talk about their successes and difficulties. The teachers made sure to emphasize that it was okay to have to keep on trying and that even our robots did not work perfectly with the light sensors. Remarkably, a few pairs did create working programs by the end of the day, and the rest at least learned a valuable lesson in emotional regulation and perseverance.

Mastering Concepts of Computer Programming: Earning "License"

Once the children had learned the robotics content, the second phase of the curriculum was a final project for children to explore how to express, through their robots, a sense of Jewish identity. The Mi Ani (Who am I?) project allowed the children to use their knowledge of robotics creatively to design and program personalized robots representing their own journeys through the school year. Each individual robot would traverse a linear timeline of large "month" posters filled with photographs of the students from each month of the year and would stop at three months of the child's choice. At each point, the robot would perform a series of actions that corresponded to the child's interpretation of a memorable school event that month. Here the students were given an open-ended opportunity to express their identities and experiences, and were encouraged to be creative, playful, and imaginative. In some ways, the thought process shifted here from the traditional Engineer Design Process to the Creative Thinking Spiral (imagine, create, play, share, reflect), which emphasizes imagination and reflection over solving a problem (Resnick, 2007).

Before the Kindergarteners began their final projects, they were required to demonstrate essential robotics and programming tasks to a teacher in order to earn their "licenses". Since we had observed that many students still had not grasped some of the robotics and programming concepts or relied on their partner for programming their robot, the teachers decided to use the license as an individual assessment method and right of passage to being able to progress to the Mi Ani projects. The students received stickers on notecards for successfully completing such tasks as building a sturdy robot, connecting wires correctly, creating a working program, and uploading the program to the robot. Having concrete tasks presented step-by-step and with immediate gratification dramatically improved the Kindergarteners' motivation and performance. In contrast to most other lessons, almost every student remained on task until she had completed her license, and most partners were able to negotiate taking turns with the robot, even when they had not worked well together in the past.

The licenses proved to be a wonderful assessment tool to ensure that everyone was at least at a baseline understanding of the robotics and to boost the students' confidence and motivation with a sense of personal achievement and mastery. It is worth noting that at the beginning of the curriculum, most students were drawn to the blocks as their choice of interface, but by the time they arrived at the license phase, every student had switched over to the graphical interface to complete the tasks. Perhaps the tangible blocks was the appropriate interface to initially transition the Kindergarteners to robotics because the coded blocks closely resembled familiar toys they were used to playing with. However, once the students were comfortable enough with the abstract concepts of programming, they likely favored the graphical interface because of its convenience. This switch is significant because it suggests that the Kindergarteners had achieved a sense of symbolic representation – they could view the 2-dimensional squares on the computer screen as abstract representations of their 3-dimensional tangible blocks.

Mi Ani?: Personalization and Mindful Planning

Once the children were cleared to start their Mi Ani projects, they were shown how to change the "channel", or program number, on the RCX so that each partner could create and upload his separate program onto different memory slots in the same robot. To further provide the students with a sense of identity and ownership for their robots, each child created her own platform reflecting her identity, which she would secure to the robot when running her program. The students were provided with a wide range of arts and crafts materials, including Plasticine modeling clay, paper, markers, colored wires, and Lego with which to design their platforms. The platforms provided an opportunity to combine robotics with traditional arts and crafts materials and were also key to the children's sense of ownership and personal investment in their projects. The children utilized diverse designs and materials, with images ranging from favorite foods, animals and colors to symbols of their religious identity, such as Jewish stars. Many students also drew JCDS signs, demonstrating a strong sense of community and close identification with their school.

The children brainstormed significant events and activities from each month of the school year with their head teachers, looking at photographs that the teachers had taken to document their experiences. Each child eventually chose three favorite events from different months and filled out her own design journal to plan out their robot's program by gluing down paper cut-outs of the blocks. The design journals also contained the child's explanation of the chosen event and the meaning behind the robot's actions. Although most of the students' programs inevitably changed from the original plan, the design journals were extremely helpful in making the programming stage more efficient because students had already formulated ideas before sitting down at the computer. The guiding questions in the journal also emphasized the reflective nature of the project, helping the students remember that their programs needed to be thoughtfully and meaningfully planned.

For the week leading up to the Mi Ani final presentation, students moved between several stations: choosing photos to decorate posters for the months, working on design journals, and programming their latest event. As the children began programming their robots, most of them opted for simplicity until they were urged to revise or modify their programs by a teacher. For example, students would put a series of five forwards in a row instead of using only three blocks in a repeat loop to achieve the same motion (REPEAT/5/FORWARD). Once prompted by a teacher or researcher, most of the children demonstrated sufficient knowledge of how to utilize the repeat blocks.

The personal investment that children had in their Mi Ani projects motivated each student to put more effort into her own robot and program than they had for previous lessons with their partners. Although many students noticeably developed more self-regulation and patience in the face of obstacles over the course of the curriculum, their personal interest in their project's success sometimes made failures more devastating.

Student Achievements in Expressing Their Identity through Robotics

Overall, the students came up with thoughtful programs and indicated that they had sufficiently internalized the robotics concepts to create meaningful robotic avatars of themselves. The children were able to narrate and explain the programs they had created to make their robots stop and perform actions that represented experiences they remembered from the school year. For example, one girl explained that "In September, on the first day of gym, [my robot] shakes...It's not letting anyone tag it." Through her narrative, this child demonstrated her understanding that her robot's programmed actions represent a memorable event in one of her favorite classes, and that this event can be narrated like a story.

Another student demonstrated her conceptual integration of the robotic program and her self-representation by personally acting out some of her robot's actions as she watched it move, such as shaking her head with the robot's shaking motion. Her creative narration also indicated a thoughtful intentionality in the program she created ("So in September, I was looking for my name [tag] so I turned. I put my light on and off because I was like, 'Bingo'"). Her use of the first person for her robotic avatar emphasized her internalization of its representational function.

The programs represented a creative combination of actions and emotions (Libman, 2011). In addition to the concrete use of actions, such as "sing" to represent singing a favorite Hebrew song, one student used "spin" to show her excitement at meeting a favorite teacher, while another student's robot moved forward and backward to represent her rolling pin flattening dough for matzah. A few exceptional programs were even more abstract, representing students' emotions using symbolism and imagery. For example, one boy's robot shook and then spun to represent the overwhelming experience of tasting a bitter lemon during Citrus Fruits Explorations. Another child created a program to turn the robot's lights on and off at the stop for her birthday celebration to represent the metaphoric idea of her eyes "lighting up" in excitement.

Overall, one of the most challenging aspects of the project emerged after all three stops were programmed separately: the children had to compile their three programs into one long journey, arrange their events chronologically and get their robots to travel the correct distance (and in a straight line) between each event so that it stopped at exactly the right months. This required extensive trial-and-error, with the children programming a certain number of forwards, testing out their robot with the line of posters representing the months of the year, and modifying the programs accordingly.

This task proved quite challenging for many of the Kindergarteners, because they did not yet possess the estimation skills to guess how many forwards would correspond to a certain distance for the robot to travel. An unrelated complication was that the robots themselves did not travel exactly in a straight line, and required the children to closely follow them, nudging them in the right direction every few seconds. Between hitting the wall or being nudged too forcefully, robot wheels and platforms would often fall off in the testing phase, which caused significant delays in the program revision process.

On the final presentation day, parents and relatives of each child were given a handout of the child's explanations of each event and program. The handout considerably helped to orient family members, as many of the Kindergarteners were not yet able to coherently verbalize their projects. The parents were amazed to see their child's robot travel the poster time line "by itself" and the students showed a clear sense of pride and confidence in demonstrating and explaining their robot's behaviors to their families. Interestingly, some students narrated their robot's journey in the third person ("My robot is doing...") while others used the first person ("Now I am going..."). This difference suggested a developmental divide between those Kindergarteners who had grasped the representational concept of the Mi Ani project and fully identified with their robot, as opposed to those who considered their robot a third party that was simply duplicating their past actions.

Post-Curriculum Assessment

Children were assessed on the thoroughness of their understanding and application of core concepts and skills using the TangibleK assessment form, a 6-point Likert scale. See Table 2 for the interpretation of each point of the scale.

This assessment tool evaluates concepts and skills derived from programming the robots as part of the TangibleK curriculum. For each of the curriculum's six activities (defined in Table 1), the children were presented with a series of tasks involving either verbal explanation or physical manipulation of the robots or the programming blocks. Their responses were systematically coded using the above Likert scale for demonstrated understanding and implementation of a set of core concepts relevant to each particular curriculum unit. For example, for the "Loops and Parameters" unit, a student might be asked to

Table 2. Definition of the six points of the Likert scale used in the TangibleK assessment form

5	4	3	2	1	0
Complete Achievement of goal/task/ understanding	Mostly Complete Achievement of goal/task/ understanding	Partially Complete Achievement of goal/task/ understanding	Very Incomplete Achievement of goal/task/ understanding	Did Not Complete goal/task/ understanding	Did not attempt/ Other

arrange a set of programming icons to tell the robot to turn four times. To code the student's response, a Likert score would be determined for each of several core concepts, including "Knows when and how to use Repeats," "Selects the right instructions," and "Arranges instructions in the correct order." If applicable, the student's debugging skills for each set of tasks would be evaluated by generating Likert scores for core concepts such as "Recognizes incorrect instructions" and "Attempts to solve the problem."

Many children in the class achieved a high level of comprehension in the application of the powerful ideas related to robotics and programming over the course of the curriculum's six activities and culminating in the Mi Ani project. Regardless of how completely they understood the more abstract concepts of the project, the Kindergarteners showed confidence in their programming skills during post-assessments ("This is so easy"; "I already know I did it right"), even if they actually made a few mistakes in terms of programming syntax. Nonetheless, it was clear that by the completion of the curriculum all of the children understood the logic of the program blocks they were taught.

In the first three curriculum activities, which introduced the engineering design process, robotics, and control flow by sequencing instructions, children's levels of achievement on most skills were particularly high (77% on average achieving "complete" or "mostly complete" understandings). One notable exception was the connection of robotic parts (i.e. connecting tiny wires) which was more difficult for small hands (achievement level was 44% on this task). In the last three activities, which introduced the more sophisticated programming concepts of loops and parameters, sensors, and branches, fewer children (41%, on average) attained the same high level of understanding.

For instance, more children achieved the highest scores on properly sequencing instructions when the programming activities involved only action instructions (71%) as compared to activities which necessarily involved the conceptually and functionally more complicated control flow instructions, or sensors (44%). Programs that use special control flow instructions look linear, but the robot does not carry out one action per programming block, as it does with a program containing only action instructions. This introduces a conceptual complexity to programming with control flow instructions that does not exist with action instructions alone. These differences in achievement reflect the relative theoretical difficulty of each programming structure, with conceptually simpler structures being more conducive to understanding than more complex ones.

The fact that fewer children achieved the highest levels of understanding on more complex topics than on the introductory concepts might indicate that more time is necessary for children to explore the harder material in order to fully understand it. Exposure to concepts makes a difference. For example, after initial introduction to "repeat" instructions, 38% of children achieved a high level of understanding, compared to after their final Mi Ani projects where 86% of children achieved a high level of understanding. Scores on correspondence (matching a programming instruction to intended robot actions) increased from 60% at the curriculum's introduction to 94%

after completing the Mi Ani project. Scores on both correspondence and sequencing decreased as activities introduced increasingly complex programming concepts–correspondence decreased to 36% and sequencing decreased to 39%. However, sequencing scores in the Mi Ani project saw a similar jump to that of correspondence scores, with 100% of children achieving a high level of understanding. During the open ended Mi Ani projects, children were able to choose a level of challenge that matched their abilities, leading to a program that was comfortable for each child and led to maximum success.

Analyzing the Experience through the PTD Theoretical Framework

The use of technology in the classroom should be guided by a particular pedagogical stance or theoretical framework. In the Mi Ani project, the PTD (Positive Technological Development) framework guided the design of the educational experience. PTD is a natural extension of the computer literacy and the technological fluency movements that have influenced the world of educational technology in the last thirty years by adding psychosocial and ethical components to the cognitive ones (Bers, 2008; Bers, 2006; Bers, 2010a). PTD provides a model for developing and evaluating technology-rich programs.

From a theoretical perspective, PTD is an interdisciplinary approach that integrates ideas from the fields of computer-mediated communication, computer-supported collaborative learning, and constructionist learning and views them in light of research in applied development science and positive youth development. Informed by both Constructionism (Papert, 1993) and Positive Youth Development (Phelps et al., 2009), PTD is a multi-dimensional framework that proposes six C's of positive behaviors supported by new technologies: content creation, creativity, communication, collaboration, community building and choices of conduct (Bers, 2010b). As a framework to guide the design and implementation of educational interventions, PTD takes into consideration the learning environment and the pedagogical practices, as well as cultural values and rituals, that mediate teaching and learning (Rogoff, 2003; Rogoff, Turkanis & Bartlett, 2001). The following paragraphs summarize the Mi Ani experience in light of the 6 C's of PTD.

Content creation is strongly supported by the CHERP software, with which children were able to program robots through either a graphical or tangible user interface. With directed challenges in the early phase of the curriculum and then in dealing with their own goals for their Mi Ani projects, the children developed competence in the technological domain and learned valuable problem-solving skills, logical thinking, and how to debug and revise their programs, while engaging in developing computational thinking.

The open-ended nature of the Mi Ani project was successful in fostering ***creativity*** in the ways the children used the technology. Although explicit lessons and challenges were initially helpful in teaching and demonstrating uses of robotics, they offered limited outlets for creativity in the solutions. However, children found extremely creative ways to express their identities and experiences when given the freedom to do so. As they had time to creatively explore and gain competence in navigating CHERP, the Kindergarteners also gained a strong sense of confidence in their programming abilities, which was extremely evident in their pride as they demonstrated their projects to their families. The students' growing confidence also bolstered their ability to overcome technological frustrations when their robots malfunctioned or when CHERP froze, either by trying to fix the problem themselves or soliciting help.

The TangibleK curriculum did support ***communication*** in several ways. First, the culminating Mi Ani project communicated to parents and family a sense of identity. Kindergarteners programmed their robots as personal avatars to communicate their views of themselves as members of the Jewish people and their particular classroom. Second, children communicated with each other to overcome frustrations and share possible solutions. The Kindergarteners also engaged in ***collaboration*** by working with their peer partners to solve the robotics challenges posed to them at the beginning of the curriculum. With a wide spectrum of developmental levels and social skills children not only learned about robotics but also about team work. The final projects were shared in an open house. This served a ***community building*** purpose.

Finally, many aspects of the robotics curriculum at JCDS allowed the Kindergarteners to make ***choices of conduct***, which offer opportunities to build character. During the creation of their platforms for the Mi Ani project, children were encouraged to examine and reflect upon their defining character traits. In addition, the limited supply of materials created social challenges in which the students had the freedom to choose whether or not to act responsibly and share materials. During the first phase of the curriculum, children had to navigate sharing of responsibilities and resources with their partners, and negotiate turn-taking. In the rug area, children at the Lego bins could choose to take an excessive amount of Lego, or to take only what they needed so they could share the Lego with their peers.

CONCLUSION

This chapter describes an innovative approach, the TangibleK robotics program, to bring ideas of computer science and engineering into the early childhood classroom in a developmentally appropriate way. Furthermore, the experience described in this chapter focuses on how robotics can be used as a tool for identity exploration. By creating robotic representations of themselves, young children underwent a process of examining their beliefs and practices as members of the Jewish community in a pluralistic school. The dynamic nature of the technology allowed for expressions of actions and experiences, as opposed to only static symbols or facts.

We believe that robotics could be beneficially integrated into any receptive Kindergarten curriculum, if accomplished in a manner that is sensitive to the needs and abilities of young children. There exists some controversy as to how suitable such programs are for this grade level, and we stress that the appropriate design of the robotics technology and the integration with other areas of the curriculum is crucial to its success in the classroom. According to our data, the majority of the *Gan Nitzan* Kindergarteners did achieve high understanding on average for basic programming skills (control flow by sequencing intructions), although most had not fully grasped the more sophisticated skills of loops and parameters, sensors, and branches by the end of the curriculum. The data suggests that greater time exposure to the more complex concepts may have improved the Kindergarteners' level of understanding in these areas.

An ethnographic approach proved particularly useful in holistically evaluating the TangibleK curriculum in this context. While quantitative data demonstrates the effects of the robotics technology within the cognitive domain, the ethnographic study elucidated the potential value of the technology across less quantifiable domains such as creativity and identity exploration. Our ethnographic perspective also acknowledges the role of culture and student population on the implementation of the project. We anticipate the importance of shaping future robotics curricula around the unique culture and population group in each classroom. We recognize that the current project was carried out within a relatively homogenous group of predominantly white, middle-class, Jewish children from the greater Boston area. It is likely that these children had received significant exposure to computer technology at home and it was observed that they were all at least beginning readers by the time the program began. We imagine that these are significant factors that contribute to successful navigation of the graphical TangibleK interface and understanding of syntax and sequential nature of the programs. Such technological fluency and literacy cannot be expected of all populations of kindergarteners, such as those coming from families of lower socio-economic status, and this must be taken into account when designing the curricula. One focus of future research is the development of more affordable robotic hardware that is developmentally appropriate and that can be used with the CHERP programming environment.

In our multicultural world, projects such as this one, that offer children opportunities to explore and represent their own dynamic notion of identity, present educators and researchers with a lens into young children's conceptualization of their identity. While the experience described in this chapter was carried out with a specifically Jewish population, it is our hope that this project will be replicated with a wide range of cultural, religious, or ethnic groups.

ACKNOWLEDGMENT

The authors would like to extend many thanks to the wonderful and creative teachers who used our curriculum in their classroom for this study: Jared Matas and Miriam Newman; to their principal Ruth Gass for embracing a new venture into JCDS; to Nehama Libman for her thesis work on the Mi Ani project, and to all the students in the DevTech group, specially Louise Flannery, Elizabeth Kazakoff and Jordan Crouser for making this project possible. This research was funded by the National Science Foundation (NSF Grant DRL-0735657). Any opinions, findings, and conclusions or recommendations expressed in this article are those of the authors and do not necessarily reflect the views of the National Science Foundation.

REFERENCES

Bers, M., & Horn, M. (2010). Tangible programming in early childhood: Revisiting developmental assumptions through new technologies. In Berson, I. R., & Berson, M. J. (Eds.), *High-tech tots: Childhood in a digital world* (pp. 49–70). Charlotte, NC: Information Age.

Bers, M., Rogers, C., Beals, L., Portsmore, M., Staszowski, K., & Barnett, M. (2006). *Early childhood robotics for learning*. Poster Session at the International Conference on the Learning Sciences. Bloomington, IN.

Bers, M. U. (2006). The role of new technologies to foster positive youth development. *Applied Developmental Science, 10*(4), 200–219. doi:10.1207/s1532480xads1004_4

Bers, M. U. (2008). *Blocks to robots: Learning with technology in the early childhood*. New York, NY: Teachers College Press.

Bers, M. U. (2010a). When robots tell a story about culture...and children tell a story about learning. In Yelland, N. (Ed.), *Contemporary perspective on early childhood education* (pp. 227–247). Maidenhead, UK: Open University Press.

Bers, M. U. (2010b). The TangibleK robotics program: Applied computational thinking for young children. *Early Childhood Research and Practice, 12*(2).

Bers, M. U., & Urrea, C. (2000). Technological prayers: Parents and children exploring robotics and values. In Druin, A., & Hendler, J. (Eds.), *Robotics for kids: Exploring new technologies for learning* (pp. 194–217). New York, NY: Morgan Kaufman.

Blikstein, P., Buechley, L., Horn, M., & Raffle, H. (2010). A new age in tangible computational interfaces for learning. In K. Gomez, L. Lyons, & J. Radinsky (Eds.), *Proceedings of the 9th International Conference of the Learning Sciences,* (vol. 2, pp. 130-132).

Bodrova, E., & Leong, D. (2007). *Tools of the mind: The Vygotskian approach to early childhood education* (2nd ed.). Upper Saddle River, NJ: Prentice-Hall.

Cejka, E., Rogers, C., & Portsmore, M. (2006). Kindergarten robotics: Using robotics to motivate math, science, and engineering literacy in elementary school. *International Journal of Engineering Education, 22*(4), 711–722.

Horn, M. S., Crouser, R. J., & Bers, M. U. (2011. (in press). Tangible interaction and learning: The case for a hybrid approach. [special issue on Tangibles and Children]. *Personal and Ubiquitous Computing.*

Kazakoff, E., & Bers, M. (2010). *Computer programming in kindergarten: The role of sequencing.* Presentation at ICERI 2010 International Conference of Education, Research and Innovation, 15-17 November 2010, Spain: Madrid.

Libman, N. (2011). *Mi ani? (Who am I?): Robotics as a medium to express Jewish identity.* Master's thesis, Tufts University, Medford, MA.

Papert, S. (1980). *Mindstorms: Children, computers and powerful ideas.* New York, NY: Basic Books.

Papert, S. (1993). *The children's machine: Rethinking school in the age of the computer.* New York, NY: Basic Books.

Petroski, H. (2003). Early education. *American Scientist, 91,* 206–209.

Phelps, E., Zimmerman, S., Warren, A. A., Jelicic, H., von Eye, A., & Lerner, R. M. (2009). The structure and developmental course of positive youth development (PYD) in early adolescence: Implications for theory and practice. *Journal of Applied Developmental Psychology, 30*(5), 571–584. doi:10.1016/j.appdev.2009.06.003

Repenning, A., Webb, D., & Ioannidou, A. (2010). Scalable game design and the development of a checklist for getting computational thinking into public schools. *SIGCSE 2010: Proceedings of the 41st ACM Technical Symposium on Computer Science Education.*

Resnick, M. (2007). Sowing the seeds for a more creative society. *Learning and Leading with Technology,* (December/January): 18–22.

Resnick, M., Maloney, J., Monroy-Hernandez, A., Rusk, N., Eastmond, E., & Brennan, K. (2009). Scratch: Programming for all. *Communications of the ACM, 52*(11), 60–67. doi:10.1145/1592761.1592779

Rogers, C. B., Wendell, K., & Foster, J. (2010). The academic bookshelf: A review of the NAE report, "engineering in K-12 education. *Journal of Engineering Education, 99*(2), 179–181.

Rogoff, B. (2003). *The cultural nature of human development.* New York, NY: Oxford University Press.

Rogoff, B., Turkanis, C. G., & Bartlett, L. (2001). *Learning together: Children and adults in a school community.* New York, NY: Oxford University Press.

Wing, J. (2006). Computational thinking. *Communications of the ACM, 24*(6), 33–35. doi:10.1145/1118178.1118215

KEY TERMS AND DEFINITIONS

CHERP: Creative Hybrid Environment for Robotic Programming – A hybrid tangible programming system composed of interlocking wooden blocks specifically designed to meet the developmental needs of young children.

Ethnographic: The scientific description of the customs of individual peoples as observed from within the culture.

Graphical Interface: A representation displayed on a computer screen for communicating instructions and feedback.

Identity: The salient characteristics defining an individual's sense of self.

Positive Technological Development (PTD): An interdisciplinary educational approach that integrates ideas from the fields of computer-mediated communication, computer-supported collaborative learning, and constructionist learning and views them in light of research in applied development science and positive youth development.

Tangible Interface: A physical modality for communicating instructions and feedback.

TangibleK: A curriculum created by the Tufts University DevTech Team using developmentally appropriate methodology to teach robotics and computer programming concepts to kindergarten students.