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Dancing robots: integrating art, music, and robotics in Singapore's early childhood centers

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Abstract In recent years, Singapore has increased its national emphasis on technology and engineering in early childhood education. Their newest initiative, the Playmaker Programme, has focused on teaching robotics and coding in preschool settings. Robotics offers a playful and collaborative way for children to engage with foundational technology and engineering concepts during their formative early childhood years. This study looks at a sample of preschool children ($N = 98$) from five early childhood centers in Singapore who completed a 7-week STEAM (Science, Technology, Engineering, Arts, and Mathematics) KIBO robotics curriculum in their classrooms called, "Dances from Around the World." KIBO is a newly developed robotics kit that teaches both engineering and programming. KIBO's actions are programmed using tangible programming blocks—no screen-time required. Children's knowledge of programming concepts were assessed upon completion of the curriculum using the Solve-Its assessment. Results indicate that children were highly successful at mastering foundational programming concepts. Additionally, teachers were successful at promoting a collaborative and creative environment, but less successful at finding ways to engage with the greater school community through robotics. This research study was part of a large country-wide initiative to increase the use of developmentally appropriate engineering tools in early childhood settings. Implications for the design of technology, curriculum, and other resources are addressed.

Keywords Robotics · Early childhood · STEAM · Programming

Introduction

Around the world children are growing up with digital devices and innovative technologies that are influencing the culture they are immersed in as well as their own personal development (Berson and Berson 2010; Buckleitner 2009; Calvert et al. 2005; Chiong and

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Shuler 2010; Couse and Chen 2010; Kerawalla and Crook 2002; Lisenbee 2009; Lonigan & Shanahan 2009; Rideout et al. 2011). As technologies are becoming increasingly present in home settings (Common Sense Media 2013), the use of educational technology in school settings has also expanded accordingly in recent years. In the United States, new federal initiatives have been making computer science and technological literacy a priority for young children (e.g. U.S. Department of Education 2010). In 2014, U.S. President Barack Obama brought public attention to coding and technology when he wrote his first line of Javascript and became one of over 100 million people worldwide to have participated in Code.org's "Hour of Code" event. In 2016, President Obama unveiled a plan to give students all across the U.S. a chance to learn computer science (White House 2016). During this time there has also been a rise in interest among non-profits and other organizations bringing computer science to elementary schools across the U.S. through institutions like Code.org and the Code-to-Learn Foundation (Portelance et al. 2015).

Outside of the U.S., a growing number of other countries and regions, such as the United Kingdom, have established clear policies and frameworks for introducing technology and computer programming to young children (Siu and Lam 2003; UK Department of Education 2013). The United Kingdom released a national curriculum framework in 2013 that included computing as an educational domain that needed to be addressed in school beginning in early childhood. In other countries, such as Finland, beginning in 2016 all primary school students will be required to learn programming (Pretz 2014). Some schools in Estonia are teaching programming to children as young as six, and other countries, such as Italy, Australia, and New Zealand are working on changing their curricula to include computer science and digital technologies (Jones 2016; Pretz 2014; Trevallion 2014).

International nonprofits such as One Laptop Per Child have focused on providing children as young as six living in developing nations and poorer countries with access to technology in schools and homes. One Laptop Per Child has reached 36 countries since its launch in 2005 including Peru, Argentina, Mexico, and Rwanda (one.laptop.org; Cristia et al. 2012). In Uruguay, One Laptop Per Child has uniquely focused on very young children in preschool and first grade as part of a plan to get educational technology into the hands of young children six and under (see one.laptop.org).

Singapore has been working to update their early childhood curricula in order to keep up with this international trend and address the growing need for engineering programs in early childhood school (Pretz 2014; Digital News Asia 2015). Singapore's government recently launched the "PlayMaker Programme" initiative to introduce younger children to technology (Digital News Asia 2015). The goal of the Playmaker Programme is to provide young children (ages 4–7) with digital tools to have fun, practice problem solving, and build confidence and creativity in a developmentally appropriate way (Digital News Asia 2015).

This newly emerging international focus on early childhood may be due to new work demonstrating that from an economic and a developmental standpoint, educational interventions that begin in early childhood are associated with lower costs and more durable effects than interventions that begin later on (Cunha and Heckman 2007). When it comes to technology interventions, research suggests that children who are exposed to STEM (Science, Technology, Engineering, and Mathematics) curriculum and programming at an early age demonstrate fewer gender-based stereotypes regarding STEM careers (Metz 2007; Steele 1997) and fewer obstacles entering these fields (Madill et al. 2007; Markert 1996). These studies have led to the many new programs, initiatives, and mandates teaching computer science in preschool and early elementary school.

This paper presents the Playmaker Programme in Singapore as an individual example of the global trend in education focusing on STEM in the early years. This study examines young children's knowledge and experiences programming using the KIBO robotics kit, one of the tools implemented as part of Singapore's Playmaker Programme initiative. The research presented here examines a sample of preschool children's mastery of foundational programming concepts after having completed a 7-week KIBO robotics curriculum called *Dances from Around the World*. Because the goal of the Playmaker Programme is not only to instill technical knowledge, but also to promote a playful and collaborative environment, this study also measures the frequency of children's positive behaviors and interactions (such as collaboration and creativity) by using Bers' (2012) Positive Technological Development (PTD) framework as a guide. Specifically, this study asks the following research questions: (1) What programming concepts do preschool children master after being exposed to KIBO? (2) How engaged were children with the different aspects of Bers' (2012) Positive Technological Development framework while participating in the KIBO robotics curriculum? and (3) What was this experience like for the participating teachers? Implications for designing country-wide initiatives and evaluations for early childhood technology education are addressed.

Literature review

STEM and STEAM education in early childhood

For decades early childhood education has focused on an exploration of numeracy and the natural sciences when it came to STEM (Science, Technology, Engineering, Mathematics) education in the early years (Bers 2008; Bers et al. 2013). With the advent of new technologies, curricula, and country-wide initiatives, parents and educators have recently begun to focus on the missing "T" of technology and "E" of engineering in early childhood STEM programs (Bers et al. 2013). Amidst this focus on technology, the United States has seen a fivefold increase in ownership of tablet devices such as iPads, from 8% of all families in 2011 to 40% in 2013 (Common Sense Media 2013). State curriculum frameworks in the United States have shifted and now include requirements for gaining exposure to engineering beginning in early childhood. For example, in Massachusetts, children need to be exposed to the Engineering Design Process and practice designing solutions to problems beginning in first grade (MA Curriculum Frameworks 2016).

As technology becomes increasingly present, many researchers and educators have also expressed concern that excessive usage of computers and digital technologies may actually stifle children's learning and creativity through passive consumption (e.g. Cordes and Miller 2000; Oppenheimer 2003). In order to address these concerns, researchers and educators have begun to focus on the ways new technologies can be used to foster positive behaviors and to engage children as *creators* rather than passive *consumers* of their digital experience (Bers 2012; Resnick 2006). For example, Resnick (2006) likens the computer to a paintbrush and describes it as a medium for self-expression and creative design. Bers (2012) likens technology to a playground that has the potential to engage children socially, physically, and creatively just as traditional toys and play structures do.

In Singapore, focusing on the positive potential of technology is a major cornerstone of the country's educational technology in early childhood movement. According to the Director of Education at Singapore's Infocomm Development Authority (IDA), Singapore is trying to change the idea of what technology in preschool settings would look like, from a screen-based approach to a maker-centered approach (Chambers 2015). But when it comes to creating the "playground" environment through digital technology described by Bers (2012), traditional STEM (Science, Technology, Engineering, and Mathematics) curricula and tools do not always successfully foster the open-ended imaginative, playful, and creative behaviors that technology education has the power to cultivate.

Integrating with other disciplines, such as the arts, can help teachers more easily think about using technology to encourage creativity in young children. In order to do this, a newer acronym called "STEAM" (Science, Technology, Engineering, *Arts*, Mathematics) has expanded on STEM and is growing in popularity (Yakman 2008). The "A" of "arts" in STEAM goes beyond just the visual arts and crafts to represent a broad spectrum of the arts including the liberal arts, language arts, social studies, music, culture, and more. Studying these fields through STEM projects can have a powerful impact on how children grow and develop. For example, Maguth (2012) proposes that social studies content should also be integrated into a STEM-focused curriculum in order to promote the development of well-rounded citizens prepared for voting on ethical and social issues related to STEM. Moreover, adding the arts to STEM-based subjects may enhance student learning by infusing opportunities for creativity and innovation (Robelen 2011). New technologies, such as programmable robotics kits (described in the following section), offer unique ways to integrate the arts and creative design with traditional STEM content.

Coding and robotics for young children

Robotics and programming provide a fun and hands-on way to introduce young children to all aspects of STEM, but especially to core components of the "T" of technology and "E" of engineering that is often missing from preschool curricula in a hands-on and creative way (Bers 2008). While engaging children with the engineering design process and technology, programming robots also provides opportunities for supporting the "M" of mathematics through sequencing, estimation, and counting and the "S" of science through an exploration of sensing, cause and effect, and conducting observations (Bers 2008; Kazakoff et al. 2013).

Research suggests that children as young as 4 years old can successfully build and program simple robots while learning foundational of engineering and robotics concepts in the process (Bers et al. 2002; Cejka et al. 2006; Perlman 1976; Sullivan et al. 2013; Sullivan and Bers 2015; Wyeth 2008). Robotics can also serve to foster numerous other developmental benefits. For example, robotic manipulatives allow children to develop fine motor skills and hand-eye coordination while also engaging in collaboration and teamwork (Lee et al. 2013; Bers et al. 2013). Additionally, robotics and programming allows children to exercise meta-cognitive, problem-solving, and reasoning skills (e.g. Clements and Gullo 1984; Clements and Meredith 1992).

New robotics kits have evolved to become the modern generation of learning manipulatives that help children develop a stronger understanding of mathematical concepts such as number, sequencing, size, and shape in much the same way that traditional materials like pattern blocks, beads, and balls once did (Brosterman 1997; Highfield et al. 2008; Kazakoff et al. 2013; Resnick et al. 1998). Unlike many digital games developed for children, building with robotics does not typically involve sitting alone, in front of a screen (Sullivan and Bers 2015). Similar to like traditional wooden building blocks and toys like Lego, robotic manipulatives allow children to develop fine motor skills and hand-eye coordination (Resnick et al. 1998).

While many educational robotics programs focus on high intensity tasks and competition, robotics also offers the possibility of engaging children in collaboration and peer discussions (Lee et al. 2013). Some newer STEAM initiatives that tie robotics in with the arts have taken a different approach that focuses on creativity and fostering an inclusive environment (Hamner and Cross 2013). When developing the robotics initiative described in the following section, activities were selectively chosen to promote this type of creative and collaborative learning through robotics, as opposed to the competitions characteristic of many other robotics initiatives. However, tools were also chosen so that they would provide the right level of difficulty to inspire problem-solving and perseverance amongst the students.

The playmaker programme in Singapore

In order to address the growing need for new educational technology programs in early childhood classrooms, Singapore's newly launched PlayMaker Programme was released in line with a master-plan to introduce younger children to technology (Chambers 2015; Digital News Asia 2015). According to Steve Leonard the Deputy Chair of Singapore's Infocomm Development Authority (IDA), "As Singapore becomes a Smart Nation, our children will need to be comfortable creating with technology" (IDA Singapore 2015). Capitalizing on the growing STEAM movement, the goal of the Playmaker Programme is not only to promote technical knowledge but also to give children tools to have fun, practice problem solving, and build confidence and creativity (Chambers 2015; Digital News Asia 2015).

As part of the PlayMaker Programme, 160 preschool centers across Singapore were given a variety of technological toys that engage children with robotics, programming, building, and engineering including: BeeBot, Circuit Stickers, and KIBO robotics (Chambers 2015). In addition to the release of new tools, early childhood educators also received training at a 1-day symposium on how to use and teach with each of these tools (Chambers 2015). These pilot schools also receive ongoing tech support and assistance with curricular integration as part of this holistic approach (IDA Singapore 2015).

This study focuses on evaluating the learning and engagement outcomes of one of the Playmaker tools implemented: the KIBO robotics kit. KIBO is a robotics construction kit designed specifically for children ages 4–7 to learn foundational engineering and programming skills (Sullivan and Bers 2015). The features of the KIBO kit and how it was used is described in detail in the "Methods" section. In addition to evaluating what technical concepts children master with KIBO, this study also examines the potential of KIBO robotics to promote positive personal and social behaviors in young children. Finally, it describes the experience from the teachers' perspective and provides examples of successes and areas to improve upon in future work. These are being offered as "lessons learned" from this pilot year of Singapore's Playmaker Programme that may be useful not only for future work in Singapore, but in other countries developing new programs for early childhood education.

Methods

This study uses a mixed-method design that includes data collected from a sample of preschool students and their teachers living in Singapore. It analyzes quantitative data (i.e. student's scores on programming assessments and frequency of behaviors observed) as well as qualitative data (i.e. teacher interviews and journals) in order to present a full picture of the robotics experience. It is important to include qualitative measures in order to capture teacher opinions, feedback, and experiences that are more nuanced and cannot be captured through solely quantitative measures.

Research overview

This study asks the following research questions:

1. What programming concepts do preschool children master after being introduced to KIBO?
2. How engaged were children with the different aspects of Bers' (2012) Positive Technological Development framework while participating in the KIBO robotics curriculum?
3. What was this experience like for the participating teachers? What areas of this initiative did they feel were successful and what areas need improvement?

Sample

A total sample of $N = 98$ young children from five preschool centers in Singapore participated in this research. Children ranged between 3 and 6 years of age at the start of this study, with a mean age of 4.9 years. The centers included a representation of public, private, and religious school settings. Five teachers (one from each of the participating schools) were also active participants in this research. Additionally, their co-teachers, assistant teachers, principals, and other staff contributed to informal interviews and feedback whenever possible in order to gain a fuller picture of what this experience was like for the schools.

Procedure

Teachers from the five preschool centers participated in a 1-day training on using the KIBO robotics. During this training, the teachers were also introduced to the *Dances from Around the World Curriculum*, developed by the DevTech Research Group, and all assessment measures and activities they would need to implement. *Dances from Around the World* is a KIBO robotics and programming curriculum that promotes an integration of technology and engineering concepts with an exploration of music and culture. Upon completing this training, teachers came up with their own adaptation of the curriculum and a calendar plan for their classes. Teachers generally taught the robotics curriculum approximately once a week for 1 hour. All schools completed a minimum of five lessons and a final project, while some schools completed eight or more sessions with KIBO. One of the goals of this project was to allow teachers to gain confidence adapting and teaching robotics in their own way to meet the needs of their students, therefore they were encouraged to make changes rather than adhere to a strict implementation plan.

Data was collected on students' programming knowledge at the midpoint and endpoint of curriculum implementation. Data was collected on students' engagement with PTD behaviors during each robotics session. These measures, including scoring and analysis, are described in the "Assessments" section of this paper.

Robotic technology

This project utilizes the KIBO robotics kit, created by the DevTech Research Group through funding from the National Science Foundation. Through KinderLab Robotics, KIBO was made commercially available through a successful Kickstarter campaign in 2014. KIBO is a robotics construction kit that involves hardware (the robot itself) and software (tangible programming blocks) used to make the robot move (Sullivan and Bers 2015). KIBO is unique because it is explicitly designed to meet the developmental needs of young children. The kit contains easy to connect construction materials including: wheels, motors, light output, and a variety of sensors (see Fig. 1).

KIBO is programmed to move using interlocking wooden programming blocks (see Fig. 2). These wooden blocks contain no embedded electronics or digital components. Instead, KIBO has an embedded scanner in the robot. This scanner allows users to scan the

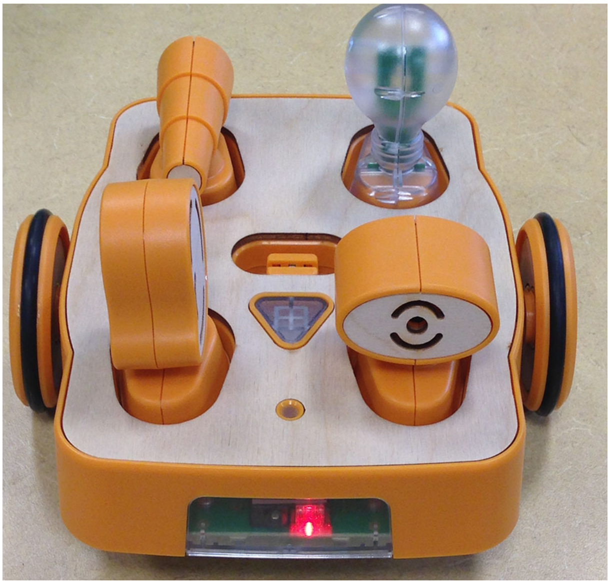

Fig. 1 KIBO robot with sensors and light output attached

Fig. 2 Sample KIBO program. This program tells the robot to spin, turn a blue light on, and shake

barcodes on the programming blocks and send a program to their robot instantaneously. No computer, tablet, or other form of "screen-time" is required to learn programming with KIBO. This is aligned with the American Academy of Pediatrics' recommendation that young children have a limited amount of screen time per day per day (American Academy of Pediatrics 2016). KIBO's block language contains a total of 18 different individual programming blocks for children to learn, with many increasingly complex programming concepts that can be introduced including repeat loops, conditional statements, and nesting statements. Recent research KIBO has shown that beginning in pre-kindergarten children are able to master foundational sequencing concepts using KIBO's programming language (Sullivan and Bers 2015). This study also found that as children got older, they were able to master more complex concepts such as repeat loops and conditional statements (Sullivan and Bers 2015).

In addition to these robotic and programming components, the KIBO kit also contains art platforms that can be used for children to personalize their projects with crafts materials and foster STEAM integration (see Fig. 3).

Curriculum

Overview

Exploration of the KIBO robot was situated within a curricular unit called "Dances from Around the World." The *Dances from Around the World* unit is designed to engage children with STEAM content through an integration of music, dance, and culture using engineering and programming tools. This unit was chosen specifically to appeal to the multicultural nature of the Singaporean community. Singapore has a bilingual education policy where all students in government schools are taught English as their primary language. In addition to English, students also learn another language called their "Mother Tongue," which might be Mandarin, Malay, or Tamil. Because the students in Singapore speak different languages and have different cultural backgrounds, the *Dances from Around* curriculum easily integrated into cultural appreciation and awareness units already typically taught in the preschool classes.

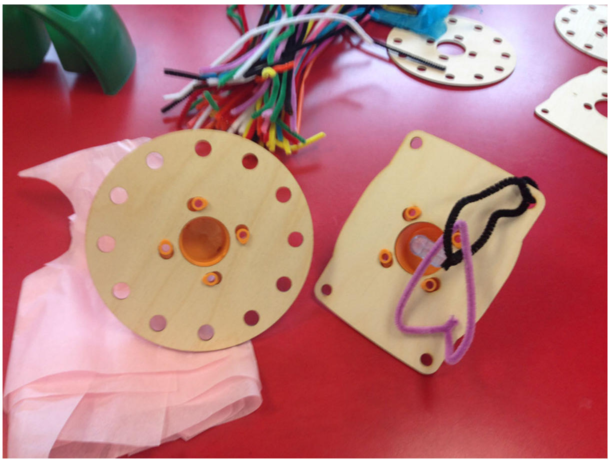

Fig. 3 KIBO's customizable art platforms

Over the course of approximately 7 weeks, teachers introduced their students to a new robotics or programming concept through weekly lessons. Each of the lessons connected to the theme of music, culture, or dance in some way. For example, in one lesson, children learned how to sing and dance the Hokey-Pokey and then programmed their robots to dance the Hokey-Pokey with them. Lessons took place for approximately 1 h once a week, leading up to a final project. Concepts from basic sequencing through conditional statements were covered.

Final robotics projects

For the final project, students worked in pairs or small groups to design, build, and program a cultural dance from around the world (see Fig. 4). This activity drew on the cumulation of students' knowledge throughout the curriculum. By the culmination of the final project, all groups had a functional KIBO robotics project that they were able to demonstrate during the final presentations.

All groups used at least two motors and were successful at integrating arts, crafts, and recycled materials to represent the dance of their choosing. Many groups also used sensors and advanced programming concepts such as repeat loops and conditional statements. Students and teachers were also successful at integrating the arts in other ways through music, dance, costumes, and performances (see Table 1 for examples).

Fig. 4 Sample decorated *Dances from Around the World* final project. This project is designed to represent Indian dancers

Table 1 Dances from around the world sample final projects

Themes	Examples
Robots were decorated to represent different ethnicities in Singapore	 
Some children dressed up in clothing to represent the same cultures their robots were representing. They performed along with the robots	
Dances from all over not just Singapore, were represented. Some students programmed their robots to dance to music from pop culture and movies, like Disney's *Frozen*	

Theoretical framework

Development and implementation of the *Dances From Around* curriculum was rooted in the Positive Technological Development Framework (PTD) developed by Bers (2012). PTD is an extension of the computer literacy and the technological fluency movements that have influenced the world of education but adds psychosocial and ethical components to the cognitive ones. From a theoretical perspective, PTD is an interdisciplinary approach that integrates ideas from the fields of computer-mediated communication, computer-supported collaborative learning, and the Constructionist theory of learning developed by Seymour Papert (1993), and views them in light of research in applied development science and positive youth development. As a theoretical framework, PTD proposes six positive behaviors (six C's) that should be supported by educational programs that use new educational technologies, such as KIBO robotics. These are: communication, collaboration, community building, content creation, creativity, and choices of conduct (i.e. making decisions and positive behavioral choices). The *Dances from Around the World* curriculum was designed to foster each of these six C's. For example, in order to foster collaboration and communication, the activities were set up for children to work in pairs or small groups. In order to foster community building, the curriculum culminated with an Open House presentation that was open to the larger school community.

Assessments

Solve-Its

The "Solve It" assessment was administered to measure students' understanding of the programming concepts taught with KIBO at the end of the curriculum implementation. The Solve-Its were developed to examine young children's knowledge of foundational programming concepts (Strawhacker et al. 2013; Strawhacker and Bers 2015). This assessment is intended to test students' mastery of programming concepts, from basic sequencing through conditional statements. The Solve-It tasks require children to listen to stories (that are read aloud by a researcher) about a robot and then spend 3–5 min attempting to create the robot's program using programming icons on paper, For example, one story is about the bus from the children's song "Wheels on the Bus" (Strawhacker et al. 2013; Strawhacker and Bers 2015) (see Fig. 5). For each Solve-It task, children were provided with all of the paper programming blocks they needed to solve the task. Solve-Its were scored using a 0–6 point scoring rubric that assigns points based on how close to correct the child's answer was. For example, a score of 6 would indicate a Solve-It that is both syntactically correct and correctly matches the order of events in the story.

This study analyzes Solve-It tasks that were administered to address different foundational concepts. These include the following: (1) Easy Sequencing, (2) Hard Sequencing, (3) Easy Repeat with Numbers, (4) Hard Repeats with Numbers, and (5) Using the Wait-For Clap block. Tasks were labeled "easy" or "hard" based on how many blocks children were required to use to complete the task (i.e. more blocks = harder task). Solve-Its were collected at the mid-point of curriculum implementation (Mid-Test) as well as at the end of implementation (Post-Test). While some of the same concepts were assessed at the mid and post test, different stories and blocks were used. A pre-test was not implemented because none of the children were introduced to KIBO or KIBO's programming blocks prior to the start of this study and the Solve-Its require basic KIBO knowledge to complete.

All tasks were tested out with the teachers as well as some accompanying principals and other school staff to determine the cultural appropriateness of these stories and songs for use in Singapore. The teachers themselves were also trained on implementing each of the Solve-Its so that it could be administered as a class curricular activity rather than a task administered by a researcher. This method of implementation was chosen to continue fostering the natural class environment, as opposed to having an unfamiliar researcher implement the Solve-Its, which may have distracted the children or made them unusually nervous.

Fig. 5 Sample child-completed wheels on the bus Solve-It

PTD Engagement Checklists

The "PTD Engagement Checklist" is a classroom assessment based on the theoretical foundation of Bers' (2012) Positive Technological Development (or "PTD") which served as the guiding framework for the *Dances from Around the World* curriculum implemented in this study. This checklist was used by researchers to document the frequency of six positive behaviors (or "six C's") set forth in the PTD Framework including: (1) communication, (2) collaboration, (3) community building, (4) content creation, (5) creativity, and (6) choice of conduct.

For each of the Six C's, researchers looked for specific behaviors and marked the frequency this behavior was observed during the robotics lesson using a 1–5 scale (1 = Never and 5 = Always). For example, for Collaboration, researchers marked the frequency that they observed behaviors such as, students lending materials to one another and students receiving help from one another. The checklist was completed by a trained researcher at the end of each lesson of the KIBO curriculum. The 1–5 scores were averaged into a total score for each of the Six C's for each lesson. Finally, the scores were also averaged across all lessons for a total composite score for each of the Six C's at the end of the curriculum.

Teacher interviews and journals

After each robotics session, teachers completed a short journaling exercise that consisted of five reflection questions that prompted teachers to think about the successful and/or challenging moments during the day's class and to describe the ways they adapted and personalized the *Dances from Around the World* curriculum to meet their students' needs. Finally, it gave them a space to write down anything else they wanted to share that was not captured by the structured questions.

In addition to this journal, teachers were also interviewed at the mid-point of their curriculum implementation by a researcher. These interviews were open-ended and unstructured with the goal of hearing the teachers' perspective on the KIBO robotics program thus far and to determine if they needed any additional supports for the remainder of the study.

Results

Solve-Its programming assessment

Students' Solve-Its were analyzed in order to determine their level of mastery of the programming concepts taught throughout the *Dances from Around the World* curriculum. Solve-Its were implemented in two waves: midtest and posttest and these results are described here.

Solve-Its mid-test

Children's knowledge of basic programming concepts were tested during the middle of curriculum implementation using the Solve-Its Programming Assessment developed by the DevTech Research Group. Students were only tested on the basic programming concepts that they had already covered up to that point (sequencing, repeats with numbers, and wait for clap). Tasks were called “easy” or “hard” based on how many programming blocks they utilized (i.e. “hard” solve its required more programming commands than “easy” ones that target the same concept). The Solve-Its were scored on a scale of 0–6 based on how close they were to the correct answer.

On average, students scored extremely high on all five concepts that were implemented at the mid-test, with mean scores of 5 or higher (out of a possible 6) on all tasks (see Table 2). This demonstrates a high level of mastery at the midpoint of the curriculum even before having extensive time to practice concepts during the final project.

Solve-Its post-test

At the post-test children were administered Solve-Its again to determine what concepts they mastered by the end of curriculum implementation. Once again, results demonstrate a very high level of mastery on all concepts taught, including advanced concepts such as Repeats with Sensors and Conditional If Statements (see Table 3). On all tasks, students had a mean score of 5 or higher, out of 6 possible points. For example, on the easy sequencing task, students scored extremely high with an average close to perfect (mean = 5.96). Students scored the lowest on the most complex topic (If Statements) which they had the least practice with because it was the last lesson taught. However, even their lowest mean score (5.05 on Ifs) still demonstrated a high level of mastery.

Table 2 Mid-test Solve-Its descriptive statistics

	N	Minimum	Maximum	Mean	SD
Easy sequencing	78	2	6	5.13	1.408
Hard sequencing	76	3	6	5.67	.929
Easy repeat numbers	76	0	6	5.18	1.251
Hard repeat numbers	76	0	6	5.00	1.200
Wait for clap	77	0	6	5.61	1.205

N varies from task to task to account for children whose tasks were removed from analysis for reasons such as: they had missing blocks, they provided the wrong the blocks, issues with legibility, issues with implementation, etc

Table 3 Post-test Solve-Its descriptive statistics

	N	Minimum	Maximum	Mean	SD
Easy sequencing	82	3	6	5.96	.331
Hard sequencing	29	2	6	5.69	.891
Easy repeat numbers	78	2	6	5.36	1.032
Hard repeat numbers	82	1	6	5.49	.933
Wait for clap	82	3	6	5.94	.396
Easy repeat sensors	77	2	6	5.22	1.119
Hard repeat sensors	78	2	6	5.27	.989
Ifs	76	2	6	5.05	1.188

N varies from task to task to account for children whose tasks were removed from analysis for reasons such as: they had missing blocks, they provided the wrong the blocks, issues with legibility, issues with implementation, etc

Table 4 Paired samples statistics for Solve-Its from mid to post

	Mean	N	SD	SE mean
Pair 1				
Easy sequencing MID	5.11	76	1.420	.163
Easy sequencing POST	5.96	76	.344	.039
Pair 2				
Hard sequencing MID	5.74	27	.813	.156
Hard sequencing POST	5.67	27	.920	.177
Pair 3				
Easy repeat numbers MID	5.23	73	1.219	.143
Hard repeat numbers POST	5.49	73	.959	.112
Pair 4				
Wait for clap MID	5.59	74	1.227	.143
Wait for clap POST	5.93	74	.416	.048

Changes from mid to post

Mean scores improved slightly when it came to easy sequencing, easy and hard repeats with numbers, and the wait-for clap command (see Table 4). The more advanced concepts (repeats with sensors and conditional statements) were only assessed at the post-test and therefore could not be compared for change from mid to post.

Matched-Pairs *t* tests were calculated to determine if there were any statistically significant changes from mid to post on these Solve-Its. Results from the tests showed that there was a statistically significant increase in students' scores from mid to post on the easy sequencing task [$t(75) = -5.430$, $p < 0.0005$] and the wait for clap command [$t(73) = -2.261$, $p < 0.05$].

PTD Engagement Checklist

The PTD Checklists were used to allow researchers to keep track of the frequency with which they observed behaviors relating to the following "Six C's" described by Bers (2012): Communication, Collaboration, Community Building, Content Creation, Creativity, and Choices of Conduct (see Table 5). For example, researchers observed behaviors such as children exchanging ideas (Communication), helping each other understand how to use materials (Collaboration), sharing work with family (Community Building), using technology to make a project (Content Creation), using technology in an unexpected way (Creativity), and showing respectful behavior to peers and teachers (Choices of Conduct). Each individual behavior was scored on a scale of 1–5, with 5 representing behaviors observed most frequently and 1 representing behaviors observed with the least frequency. This was calculated for each session.

A final cumulative average score for each of the Six C's of the PTD framework was calculated at the end of the curriculum implementation. The cumulative averages demonstrate that the curriculum was most successful at fostering content creation (score of 4.1), communication (score of 4.02), and collaboration (score of 3.55). Creativity also had a relatively high score of 3.03 (see Fig. 6).

Table 5 Sample observed behaviors exemplifying the Six C's

Six C's	Sample behaviors observed on checklist
Communication	Students are exchanging ideas with others Students seek help and ask questions
Collaboration	Students borrow or lend materials Students are helping each other understand materials
Community Building	Students are volunteering to share work with others during Circle Time Students create projects to solve a social, community, or classroom problem
Content Creation	Students create a functional program for their robot Students debug problems in their program
Creativity	Students use a variety of materials for their projects (arts, crafts, technical materials such as sensors, etc.) Students use technology in unexpected or unconventional ways
Choices of Conduct	Students are following classroom rules Students are using materials responsibly

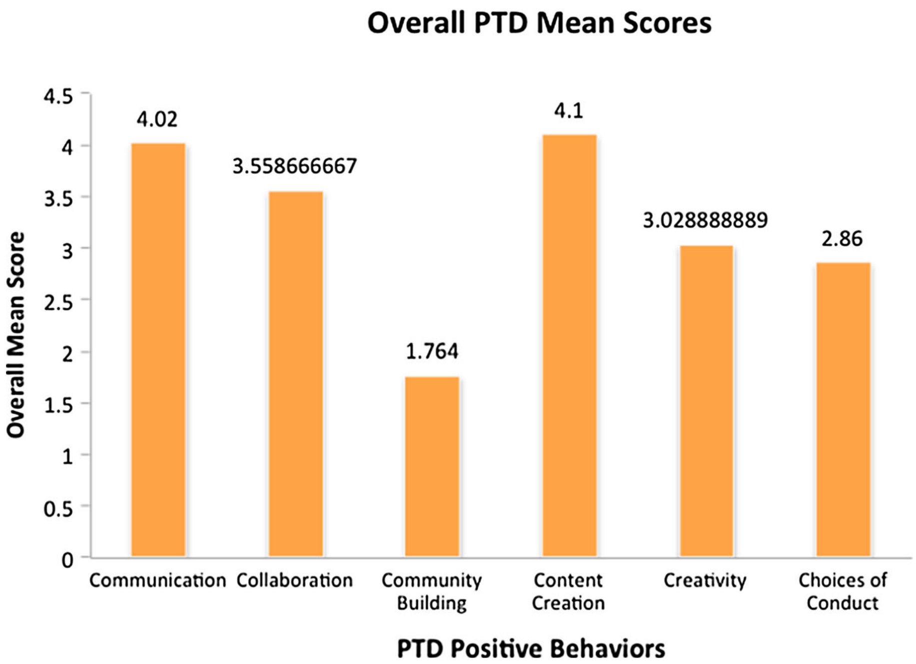

Fig. 6 Cumulative PTD scores

Teachers' experience

According to the teachers' activity reflection journals, they were generally successful at reaching their lesson goals and objectives each week of the robotics implementation. They chose to use a variety of strategies when introducing complex engineering concepts to their students. Some strategies were taken directly from the *Dances from Around the World* curriculum while others were the teachers' own creation. The following strategies came up frequently in the activity journals:

- Introducing a new concept in KIBO by showing off a song, dance, game, or story.
- Use of group discussions (full class work) mixed with small group/partner work.
- When first constructing robots, parts of robots were likened to cars and vehicles.
- Teaching sensors by relating the aesthetic design of each sensor to what the sensor's function is (e.g. Ear design = sound).

Teachers (sometimes with the assistance of other school staff) were also actively involved in adapting and modifying the *Dances Around the World* curriculum to meet the needs of their students (see Table 6). This was encouraged by the research team during the initial training, and it was suggested that teachers use the curricular activities as a "jumping off point" for the concepts to be taught. Teachers generally adapted the curriculum by doing one of the following: skipping activities, adding in new activities, adapting/changing the structure of activities, changing the schedule of when/how long activities were led, and making changes for cultural reasons.

Finally, in interviews and reflection journals, teachers shared what the robotics experience was like for them, including some of the positive moments and the challenging moments they encountered throughout the launch year of this (see Table 7). These reflections indicate that, from the teachers' perspective the experience was successful and promoting hard work and perseverance, while also allowing students to practice Bers' (2012) PTD behaviors such as collaboration and communication amongst peers. While teachers were generally novices when it came to teaching with technology, many of them commented that they were self-motivated to learn to use the technology and gain hands-on experience with it.

Despite the general feeling of success, many teachers did say they would have benefitted from longer or more training and professional development during this initiative.

Table 6 Examples of curriculum modification

Types of changes	Examples/quotes
Omitting lessons/activities	Only a few activities were hand-picked
Additions to Curriculum	Added a Fashion Parade Show which each representative to a catwalk with their KIBO dressed in traditional costume from the four races of Singapore
Adapting games/activities	For the [KIBO] Bingo game, instead of getting 3 in a row to win the game, children had to place all counters in all the icons to win the game. This was done so that children would have the opportunity to re-cap on all the icons while being engaged at the same time
Adapting the time/days spent on each aspect of the curriculum	Instead of decorating and programming on the same day, children focused only on decorating their KIBO. They will program their KIBO to dance to the cultural song during the last session next week
Cultural adaptations	The dances were more to Singaporean context e.g. lion dance [I] showed the traditional costume of the four races of Singapore (Chinese, Malay, Indian and Eurasian)—more familiar to the children as compared to the suggestion listed in the curricula

Table 7 Significant quotes from teachers

Themes	Illustrative quotes
Children showed hard work and perseverance	I liked the way some groups discussed and tried again and again when things do not work, it demonstrated perseverance and determination, boosted their confidence when the scanning or the analyzing worked on the KIBO
Teachers felt eagerness to learn even when feeling in-experienced	Even though we don't know, we're still very interested in it. We just touch it and learn and see how it works
Teachers tried to test out robotics projects before demonstrating to kids	Before actually showing it [to the kids], I would actually try it [the lesson] out first
Children showed excitement and eagerness to use KIBO	They were also eager to try and put the blocks together to create different dances
Children practiced collaborating and communicating	They participated actively on large group discussions The children collaborate with each other

This was especially true when it came to the more complex concepts such as repeat loops and conditional statements, which some teachers admitted they did not remember after completing the training. Although teachers were provided with many ongoing online resources, they expressed that with the hands-on nature of KIBO, these were not as useful as in-person practice and training.

Discussion

Summary of findings

Children's learning outcomes

The Solve-It scores demonstrate that participating students from Singapore's preschool centers had a high level of understanding of foundational programming concepts. The Solve-Its implemented assessed the following concepts taught in the *Dances from Around the World* curriculum: Sequencing, the Wait-For Clap block, Repeat Loops with Number Parameters, Repeat Loops with Sensor Parameters, and Conditional Statements. Solve-Its were scored on a 0–6 scale, and the sample had a mean score of 5 or higher on *all* of the tasks implemented at both the mid and post test. The high scores during the mid test also indicate that students were able to master new programming concepts quickly, even without extended periods of time for practice.

These scores contrast Solve-Its findings in the United States using an earlier version of the KIBO robotics kit. In findings by Sullivan and Bers (2015) preschool children scored a mean of 3 or higher on the sequencing tasks, but could not be administered the more complex repeat loop and conditional tasks because this was not covered in their curriculum because it was not deemed developmentally appropriate. The Solve-It mean scores from Singaporean preschool in this study are more aligned with the mean scores from children in first and second grade in the United States, and was generally higher than U.S. children in Kindergarten (Sullivan and Bers 2015). This could be attributed to a variety of cultural factors including classroom management and how accustomed young children are to receiving formal assessments and tasks in Singapore and the United States. Future research should further examine cultural differences in programming performance in early childhood.

The students' final robotics projects also demonstrated a high level of mastery of the building, construction, and engineering concepts introduced throughout the curriculum. Students were able to use motors, platforms, sensors, in their projects. Additionally, they were able to successfully integrate arts, crafts, and recycled materials into their final robot constructions. All students in the sample had a sturdy-built, decorated, and functional robot by the end of the curriculum implementation. In addition to including art in their designs, the final projects also promoted STEAM content integration with music and dance influencing the students' programming. Many students were engaged as choreographers for their robots as well as themselves. The nature of the final projects demonstrated a successful STEAM integration that involved several aspects of the arts including music, dancing, and fashion. It provides preliminary evidence that robotics and programming can be used as a tool to support learning of music and dance.

Finally, the PTD scores indicate that this curriculum was most successful at fostering content creation. This is not a surprise given that each lesson of the curriculum was focused on building and programming a new project. The intervention was also fairly successful at promoting collaboration and creativity, which were goals for IDA's Playmaker Programme. Future work should focus on more effective ways to use technology to promote community building and choices of conduct. In this intervention, community building was most pronounced by the end of the curriculum, when parents and other classes were invited to see the final showcases. Future interventions may look for ways to successfully integrate community building *throughout* the robotics lessons.

Teachers' experience

Results from the teachers' interviews and reflection journals indicate that this initiative was not only a positive experience for the students but for them as well. Teachers showed independence and confidence as they modified the *Dances from Around the World* curriculum to meet the needs of their students and to adapt to the Singaporean cultural context. The teachers' comments also often related back to two of the six PTD C's: collaboration and communication. Many of their comments had to do with watching their students work well together and persist when faced with challenges. One of the goals of the Playmaker Programme was to foster the "can-do spirit needed in innovation" through digital technology initiatives (Digital News Asia 2015). This observation that students were able to persevere through challenges provides initial evidence that robotics helped students and teachers work toward this goal in an organic way.

Limitations

One of the major limitations of this study was the implementation of the Solve-Its programming assessments. These assessments were implemented by the classroom teacher as a class activity, rather than a "formal" assessment implemented by the research team. Although the teachers were trained by the research team on how to implement the Solve-Its, it is possible that their implementation was biased based on knowing the data would be collected and they may have provided more help and scaffolding than intended with the Solve-Its.

There were also a large number of Solve-Its that had to be removed because students were either provided with the wrong blocks to sequence or extra blocks to sequence.

Additionally, there were a large number of Solve-Its that had to be removed from analysis because it was apparent that the teacher in that classroom may have read the stories aloud incorrectly. For example, on the Hard Sequencing Solve-It, an entire class was removed from analysis because nearly every student made the same mistake that had to do with the order of the commands (not programming syntax). Removing these students from analysis of certain Solve-Its (along with students who may have missed testing due to absences) resulted in an uneven *n* across the tasks and may have influenced the results that were produced.

These issues in Solve-Its implementation may be rooted in cultural differences in interpretation of the assessment materials and training. This is the first study in which Solve-Its were administered outside of the United States and one of the first studies in which the classroom teachers themselves implemented them as an activity (rather than a research team). Future work may need to be done to further train teachers and appropriately adapt some of the Solve-Its for use in Singapore.

Future work

This study looks at results from all of the children from the five preschool centers combined. However, teachers did not implement identical curricula in their classrooms. One of the goals of this intervention was to empower teachers to create their own versions of the *Dances from Around the World* curriculum and implement their own games and activities to teach KIBO. Results from observations and the interviews and reflection journals show that teachers were generally successful at reaching this goal. However, this means that each teachers' unique teaching style, interpretation of the curriculum, and pedagogical approaches may have had an impact on children's learning and experience with the robotics activities. Future work should look more specifically at the impact of these pedagogical choices on the experience of children. This study also focused on evaluating learning outcomes with one of the Playmaker tools (KIBO). Future work may consider comparing learning outcomes across the variety of digital tools being introduced in Singapore to determine which technologies are most successful at promoting specific domains of knowledge.

Finally, this study was conducted in Singapore in collaboration between the DevTech Research Group in the United States and the Infocomm Development Authority in Singapore. Although this study took place in Singapore, the curriculum, robotics set, and research instruments were originally developed in the United States and adapted for use in Singapore. As robotics such as KIBO are becoming increasingly popular around the world, cross cultural comparison studies may be useful to determine which concepts, tools, and pedagogical approaches have universal appeal and which are culturally specific.

Conclusion

Singapore's Playmaker Programme offers an innovative example of how one country is addressing the growing need to increase their national focus on technology and engineering initiatives during the foundational early childhood years. This study demonstrates that beginning in preschool, children can use technologies like robotics to learn fundamental engineering and programming skills that will set the stage for more complex projects and exploration in later schooling years. At the same time, the children's *Dances from Around* *the World* projects also demonstrate that the increased focus on technology in the early years does not need to involve passive screentime consumption. Just the opposite, it showcases the ease with which the arts, music, social studies, and other traditional early childhood content can be fostered through the use of new technologies. It is important to note that these gains were made possible not only through providing funding for technologies to the preschools, but through providing training and support throughout the process. Even with the level of support provided, teachers indicated that more training would have been beneficial. Future initiatives, within or outside of Singapore, should consider the need to provide not only quality technological tools and curriculum, but also quality professional development and teacher support in order to make an impact.

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