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PUT YOUR ROBOT IN, PUT YOUR ROBOT OUT: SEQUENCING THROUGH PROGRAMMING ROBOTS IN EARLY CHILDHOOD

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ABSTRACT

This article examines the impact of programming robots on sequencing ability in early childhood. Thirty-four children (ages 4.5-6.5 years) participated in computer programming activities with a developmentally appropriate tool, CHERP, specifically designed to program a robot's behaviors. The children learned to build and program robots over three sessions, of 1.5 hours duration each, in a laboratory setting. The participants' sequencing skills were assessed before and after the intervention using a picture-story sequencing task. Pre- and post-test scores were compared using a paired sample *t*-test. A significant increase in post-test scores compared to pre-test scores was found.

Young children are surrounded by technology, from electric toothbrushes to iPads. Everyday children encounter digital technologies that "know" what is going on, such as automatic paper towel dispensers that "know" when hands are waving in front or cell phones that "know" how to take pictures or play music; but very little, if anything, is taught to young children about these new technologies and how they work (Bers, 2008).

Due to advances in science and technology, such as less expensive, smaller, and more powerful batteries, chips with ever-increasing speed and memory, and

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the use of touch screens, the history of technological devices has changed dramatically in the past 40 years. Children now have access to cell phones, digital cameras, digital book readers, digital media players, tablet computers, and smart toys (Buckleitner, 2009). Current and future generations will likely grow up surrounded by these new technologies and others we have yet to imagine. As computers and other technological devices are becoming faster, smaller, and cheaper, the use of these devices is becoming more widespread having an increasing impact on young people's lives (Resnick, 2002; Shore, 2008).

Currently, 75% of all households have broadband Internet access (Pew Research Center [Pew], 2010) and around 84% of households have some access to the Internet (Kaiser, 2010). In addition 93% of children 6 to 7 live in a home with a cell phone (Sesame, 2007) and 19% of children in grades K-2 have access to cell phones with Internet connectivity (Project Tomorrow, 2009). Thirty-two percent of children in grades K-2 have access to an mp3 player, 53% of children in grades K-2 have access to a desktop computer, and 31% have access to a laptop (Project Tomorrow, 2009). In turn, 27% of 5 to 6 year olds use these computers, for an average of 50 minutes per day; using Skype to chat with grandparents, watching movies and TV shows, and playing games, to name a few examples. In one large-scale study (Rideout, Vandewater, & Wartella, 2003), parents reported children under the age of 6 spend, on average, 2 hours per day with screen media. This is the same amount of time parents reported their child played outside and almost three times as much time the child spent reading or being read to by an adult.

Despite the pervasive nature of digital technologies in the United States, North American children are lagging far behind other countries in STEM areas (Science, Technology, Engineering, and Math) (Pisa, 2006). Children more often know how to use the technologies, but do not understand how they work. Some scholars argue, in order to grow up digitally literate, children need to understand basic computer functions, in particular, programming (Jenkins, 2006; Rushkoff, 2010) and understand basic technology concepts to be able to operate technological tools by the end of second grade, or else be at a disadvantage in the 21st century workplace (ISTE, 2007).

To address these needs in early elementary school, the National Association for the Education of Young Children (NAEYC) has partnered with the Fred Rogers Center on a position statement, *Technology in Early Childhood Programs Serving Children from Birth through Age 8* (2012). This document argues that technology can promote social, linguistic, and cognitive learning, and technology interventions are most effective in early childhood settings when they are used to enhance learning and development, communication, social interactions, and collaboration. In addition, the current Obama administration identified STEM education in grades K-12 as a high priority for education and is supporting growth in these areas through programs such as Education to Innovate (US DOE, 2010a) and the National Technology Education plan (US DOE, 2010b) and partnerships with organizations, such as Sesame Street Workshop, to engage children in invention and discovery.

COMPUTERS IN EARLY CHILDHOOD EDUCATION

Computers were integrated into classrooms as early as the 1970s (Fouts, 2000). Computer-based technology has offered unique opportunities for learning through self-guided, self-paced exploration and problem-solving (Clements & Swaminathan, 1995). Developmentally-appropriate new technological tools also provide opportunities for scaffolded-learning further enhanced by interactions with parents, teachers, and peers, drawing on Vygotsky's concept of the zone of proximal development (the space between what a child can achieve on his/her own versus can achieve with assistance) (Vygotsky, 1978). Social and cultural learning may also occur based on the types technologies used, the purposes of their use, and the environment in which the technology is used. Computers are historically an area where children develop in both pro-social and cognitive ways simultaneously (Clements, 1987). This phenomenon continues with new hand-held devices, like the iPad, creating new terms like the "pass-back effect" to refer to the interactions between parent and child when using a small, hand-held digital device passed between parent and child (Shuler, 2009).

Computer-based technology also helps in the visualization of concepts that are difficult to comprehend (Fouts, 2000), making them a powerful tool for assistive and adapted curricula for both children with and without learning difficulties (Rose, Hasselbring, Stahl, & Zabala, 2005). Furthermore, studies have shown children who write at computers write more, are less worried about making mistakes, are more willing to take risks, and have fewer problems with fine motor control than children who write with a pencil and paper (Clements, 1987). In addition, a study of 122 preschool children in Head Start programs found children exposed to computers at home performed significantly higher on tests of school readiness and cognitive development, using the WPPSI-R (an IQ test) (Li & Atkins, 2004). Despite concerns of social isolation (Cordes & Miller, 2000), children actually speak up to nine times more frequently at a computer than when completing puzzles (Clements & Swaminathan, 1995) and, even if children are each given their own computer to use, typically you will see two or three children around just one screen, demonstrating the social nature of computing in classroom settings, rather than isolation (Druin, Hendler, Montemayor, Boltman, McAlister, Kowasky, et al., 1999).

ROBOTICS

New technologies, in particular robotics, make different kinds of learning opportunities possible, including new ways for peer social interactions, and many opportunities for creativity, social, and cognitive development. This article examines the impact of engaging kindergarten children in computer programming activities, in the context of programming the behaviors of robotic artifacts, as a means for teaching sequencing skills in early childhood. Robotics was chose as a domain because it makes abstract ideas more concrete, as the child can directly view the impact of his or her programming commands on the robot's actions (Bers, 2008).

Prior research has shown the benefits of integrating robotic technologies into the early childhood classroom and play in developmentally appropriate ways (Bers, 2008, 2010; Bers, Ponte, Juelich, Viera, & Schenker, 2002; Levy & Mioduser, 2010; Mioduser & Levy, 2010; Rogers & Portsmore, 2004). There is an economic benefit for educational interventions that begins in early childhood as they are associated with lower costs, and longer-lasting effects, than interventions that begin later in childhood (Cuhna & Heckman, 2007; Reynolds, Temple, Ou, Arteaga, & White, 2011). Preliminary research also suggests that children who are exposed to STEM (Science, Technology, Engineering, and Math) curriculum at an early age demonstrate fewer gender-based stereotypes regarding STEM careers (Metz, 2007; Steele, 1997) and fewer obstacles entering these fields (Madill, Campbell, Cullen, Armour, Einsiedel, Ciccocioppo, et al., 2007; Markert, 1996).

COMPUTER PROGRAMMING IN EARLY CHILDHOOD EDUCATION

This study focuses on robotics as a medium for learning the skill of computer programming. Computer programming "is a creative endeavor requiring planning, precision in the use of language, the generation and testing of hypotheses, the ability to identify action sequences, . . . and a variety of other skills that seem to reflect what thinking is all about" (Nickerson, 1982, p. 42). Computer programming has been touted as an important skill for 21st century literacy as it is the foundation of all digital technologies (Jenkins, 2006; Rushkoff, 2010). Programming, as a basic description, is a sequence of commands used to create a series of actions to instruct a computer's behavior (Pea & Kurland, 1984). In order to create a successful program, children must understand the logic of instructions and sequential thinking. When creating a program, children are thinking in terms of *next, before,* and *until* which are all components of sequencing (Pea & Kurland, 1984).

Programming languages for children began when Seymour Papert created Logo and introduced the concept of constructionist programming environments (Papert, 1980). Papert's work was largely based on the ideas of Piaget (1970) in regard to a child's cognitive development, but applied to the realm of computer technology (Goldstein & Papert, 1977). Piaget was known as the father of constructivism, the idea that knowledge is learned by interacting with one's environment and constructing and understanding about the world by these interactions. Papert created his own term, *Constructionism*, to stress the importance of physical constructions in the digital world, to represent mental thoughts (Papert, 1980). Knowledge is not just poured into a child's head or passively absorbed; the child must construct the knowledge for him or herself (Piaget, 1970). Constructionist programming environments are tools for engaging children in thinking about their own thinking; a place where abstract ideas can become more concrete and thereby subject to reflection (Papert, 1980). Although a computer was mainly used by mathematicians at the time Papert wrote about constructionism, he had a vision of the computer's power, for computers can be programmed and can be anything to anyone, taking on a "thousand forms" for a "thousand functions" and appeal to a "thousand tastes" (Papert, 1993, p. xxi).

Researchers have continued to build on the use of Logo and Papert's ideas of developmentally appropriate, constructivist programming environments for children. For example, the programming language Scratch, an object-oriented programming language, allows young children to build and share their own stories, games, and artistic creations (http://scratch.mit.edu; Brennan, Monroy-Hernandez, & Resnick, 2010; Maloney, Resnick, Rusk, Peppler, & Kafai, 2008) and CHERP (Creative Hybrid Environment for Robotic Programming), the programming language used in this study, is a graphical-tangible hybrid programming language, meaning, the child is allowed to transition back and forth between the screen-based (graphical) and tangible (block-based) programming interfaces for robots (Bers & Horn; 2010; Horn, Crouser, & Bers, 2011).

The Creative Hybrid Environment for Robotic Programming (CHERP) system allows young children to program with interlocking wooden blocks or the corresponding on-screen blocks (Figure 1) and to transition back and forth between them. The icons represent the same actions for their robots to perform in either case. This hybrid approach caters to individual preferences in interface and allows children to work with multiple representations of the programming actions (Horn et al., 2011).

Teaching children how to program with languages such as CHERP and Scratch gives them access to the tools to evaluate and create new technologies for themselves (Rushkoff, 2010) and to be producers of content (Bers, 2010; Resnick, 2001) not just passive consumers of technology created by others (Rushkoff, 2010).

Tools that engage children in computer programming, however, must be developmentally appropriate (Bers & Horn, 2010). Young children, who are in Piaget's preoperational stage, require hands-on experiences to facilitate discussion and make sense of their worlds. Using tangible items, such as blocks, might enable abstract ideas beyond their current cognitive abilities to become more concrete (Singer & Revenson, 1997). In the same spirit, Piaget hypothesized that children who learn mathematical concepts with manipulatives would be more likely to bridge the gap between the real and abstract worlds (Kennedy, 1986).

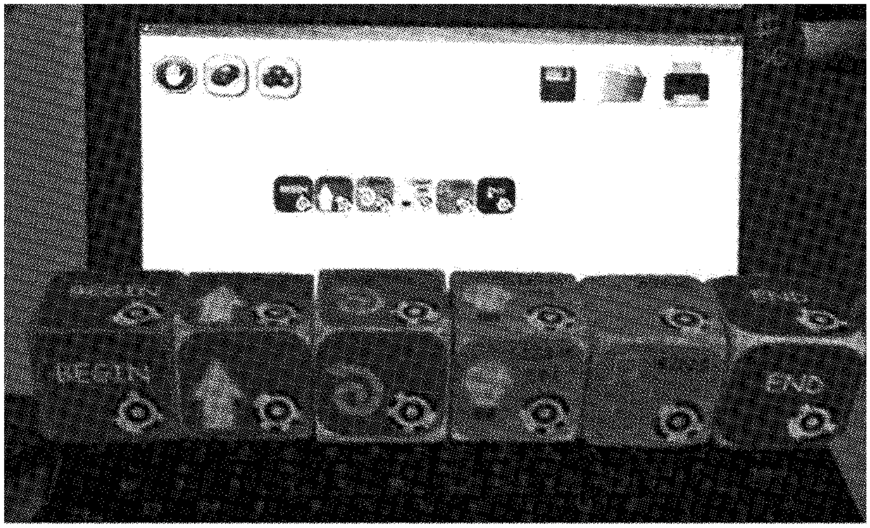

Figure 1. Two interfaces of CHERP.
Children can choose their means of programming with the hybrid tangible-graphical programming language called CHERP. This photo shows the wooden, tangible blocks and the corresponding on-screen, graphical program.

Research has shown technologies that enable children to become programmers can be powerful tools for teaching new skills and concepts (Bers, 2008; Bers & Horn, 2010; Cejka, Rogers, & Portsmore, 2006; Clements, 2002; Papert, 1980). For example, when introducing Logo in a supportive classroom environment, learning computer programming has been found to impact a wide range of cognitive skills in early childhood, including computational thinking (Clements, 1999; Liao & Bright, 1991), meta-cognition (Clements, 1986; Miller & Emilhovich, 1986) and transfer of skills in problem representation, problem-solving, and debugging (Degelman, Free, Scarlato, Blackburn, & Golden, 1986; Klahr & Carver, 1988; Salomon & Perkins, 1987). A review of early work in this field suggests children who participated in computer programming typically scored around 16 points higher on various cognitive-ability assessments compared to children who had not (Liao & Bright, 1991).

New research on innovative programming environments support the argument that children's programming of animations, graphical models, games, and robots with age-appropriate materials allow them to learn and apply core computational thinking concepts such as abstraction, automation, analysis, decomposition, modularization, and iterative design (e.g., Bers & Horn, 2010; Lee, Martin, Denner, Coulter, Allen, Erickson, et al., 2011; Mioduser & Levy, 2010; Mioduser, Levy, & Talis, 2009; Resnick, 2006; Resnick, Maloney, Monroy-Hernandez, Rusk, Eastmond, Brennan, et al., 2009). Children who used Logo in kindergarten were also found to have sustained attention, self-direction, and took pleasure in discovery (Clements, 1987). A large-scale study of children using the Logo programming language (Clements, Battista, & Sarama, 2001) demonstrated that children in grades K-6 scored significantly higher on tests of mathematics, reasoning, and problem-solving. A proposed explanation for the outcome of this study is that when children engage in computer programming activities and create a sequence of commands for the computer to read they are externalizing and reflecting upon their inner thought processes. Young children who used Logo also transferred their knowledge to a variety of logic and math domains, map reading, and interpreting the rotation of objects. Furthermore, computer programming also has some impact on social-emotional skills including creativity, particularly emotional response in children with learning difficulties (Clements, 1999; Clements & Swaminathan, 1995; Liao & Bright, 1991).

Computer programming is defined as "using . . . sequence of instructions, variables, recursion, etc. to write solutions to problems . . ." (Liao & Bright, 1991, p. 253). If sequencing is at the core of one's ability to understand and create computer programs (Pea & Kurland, 1984) and computer programming has been linked to improvement in cognitive skills (Clements, 1999; Liao & Bright, 1991), then, if the heart of computer programming *is* sequencing, can computer programming positively *impact* sequencing?

Sequencing

Sequencing is an important component of both early mathematics and early literacy learning and is a common theme in early childhood classrooms. The retelling of a story in a logical sequence, ordering numbers in the correct sequence, and understanding the sequence of a day's activities are components of curriculum frameworks for children in kindergarten in both language arts and mathematics (Massachusetts Department of Education [MA DOE], 2008). Massachusetts even includes an interdisciplinary requirement of learning and using short dance sequences (MA DOE, 1999).

In 1998, the U.S. Department of Education embarked on a plan to assess 19,000 kindergarten students to collect a baseline of what children this age know, called the Early Childhood Longitudinal Study (United States Department of Education (US DOE), 2001). This assessment included "recognizing a sequence of patterns" as a mathematics assessment measure (US DOE, 2001). This study found 58% of kindergarteners were proficient in recognizing patterns of sequence and 20% were proficient in ordinal sequencing (first, second, third, etc.) (US DOE, 2001).

In both literacy and mathematics, sequencing is essential for putting words, letters, and numbers in the appropriate order (Neuman & Dickinson, 2002). Story sequencing skills, along with vocabulary knowledge and story comprehension in kindergarten, are strongly linked to success in literacy later in life (Snow, Tabors, Nicholson, & Kurland, 1994). Constructing narratives scripts, or sequences of daily routines, are a common part of the early childhood curriculum (Paris & Paris, 2003). Sequencing problems are a contributing factor to poor reading in kindergarten as these problems impact understanding and prediction of themes, patterns, and storylines (Kamps, Abbott, Greenwood, Wills, Veerkamp, & Kaufman, 2008). Using sequenced pictures for storytelling is common in early childhood because the task requires narrative thinking and understanding of sequences, without relying on words (Paris & Paris, 2003).

In his classic work, Piaget found children younger than 6 or 7 were unable to successfully complete a story-sequencing task (Piaget, 1969). According to Piaget, children in the pre-operational stage were unable to sequence due to their inability to reason about more than one object or action at a time. He argued the ability to reason about multiple objects simultaneously, and thus be able to reverse them, was key to understanding sequencing (Piaget, 1969).

However, subsequent studies found children in kindergarten could construct sequences, and children as young as 2 can understand and imitate short (2-3 action) familiar sequences (O'Connell & Gerard, 1985) but younger children cannot necessarily discuss the logic or cause and effect related to sequenced stories (Brown & French, 1976). Criticism of Piaget's work in this area comes also in the form of his sequencing assessments themselves, which some claim were arbitrary and not grounded in meaning for the child (Brown & Murphy, 1975). When a sequencing task is presented in a meaningful context, such as a narrative, the kindergarten child is better able to sequence (Brown & Murphy, 1975).

Overall, research has shown that children in the pre-operational period may be able to sequence in a forward direction without needing to understand reversibility (Fivush & Mandler, 1985). Children in kindergarten have less difficulty with familiar sequences in the forward order, but more difficulty, even in the forward order, for events the child has not experienced first-hand. The child, in the case of inexperienced events, would have to rely on inferring logical connections between events, which is difficult for the young child in the pre-operational period (Brown & French, 1976; Fivush & Mandler, 1985).

Computer programming can be seen as creating a story through sequencing. The child translates his or her story for the robot's behaviors into a sequence of commands. With the CHERP system, 2×2 cubes of wood with pictures depicting units of code, for example, forward, backwards, right turn, left turn, light on, light off, spin, shake, sing, and beep are used to create a "story" for the robot to act out. The child can hold both the programming blocks and the robot. This ability to physically manipulate the blocks is a powerful tool for visualizing and reflecting on the sequence of a program.

This study aims to test the hypothesis that children who engage in programming activities will increase sequencing skills as measured by a picture sequencing task. This study predicts that young children who program robots with a developmentally-appropriate programming interface, CHERP, will increase in post-test picture sequencing scores compared to their baseline pre-test scores.

METHOD

Participants

Participants in this study were 34 young children from urban and suburban, public and private, local elementary schools with a mean age of 5.5 years (4.5-6.6, *SD* = 0.5). The sample was comprised of 68% males and 32% females with 29% prekindergarten and 71% kindergarten students. The average length of participation in the program was 17.8 days (*SD* = 5.7 days). The highest level of parent education was as follows: high school (3.1%), some college/2-year school (3.1%), bachelor's (34.9%), master's (35.9%), and doctorate (23.4%). Participants attended public school (35.3%), private school (61.8%), and the remaining participants (2.9%) did not respond. Participants were 68% Caucasian, 15% African American, 12% Asian, and 5% did not specify.

Parents and children were interviewed about the child's prior exposure to computers and robotics. According to both parent and child reports, none of the participants had prior exposure to computer programming. A majority of the children (73%) stated they had used a computer before with over half the parents stating the child used a computer at home (67%). Children also participated in a mouse skills assessment where the child was to use the computer mouse to drag and drop objects to specific areas of the screen. For the mouse skills pre-test, 53% of participants could successfully complete all aspect of this task, 26% could partially complete this task, 9% could not use the mouse, and 12% did not attempt the task.

Recruitment

Advertisements of the study were sent to local elementary schools via e-mail and posted as paper flyers. No fees were charged for the workshops nor was any form of compensation provided to the families beyond the experiences provided in the workshops. Participants were required to register for four sessions. Parent(s) were required to schedule all four sessions within a 1-month time frame, with no two sessions scheduled more than 2 weeks apart. Registration was conducted via an online form; however, phone and in-person registration were provided for those families who were uncomfortable with the online form. Confirmation e-mails were sent after registration and reminder e-mails were sent prior to sessions. Parents were also contacted and allowed to reschedule if a child missed a session.

Originally, 40 children were registered for the program. Three children were never brought to the initial assigned program start date and parents did not respond to attempts to reschedule. Two children did not complete the program due to their families' unexpected scheduling conflicts. One child did not complete the program due to refusal to engage in most pre-testing activities.

The participants were pre-tested during the first session in the areas of robotic knowledge, programming knowledge, sequencing abilities, reading and writing skills, Lego® building skills, computer mouse skills, and ability to give instructions. Children were also asked about their previous experience and knowledge of robotics and programming. Parents filled out a background survey to assess a participant's prior knowledge, as well as the parents', in regard to computers, programming, robotics, and experiences with Lego®.

Procedure

This study utilized an adaptation of the TangibleK program. This program integrates a 20-hour curriculum of activities, a hybrid graphical-tangible programming interface called CHERP, and Lego ® Mindstorms ® robotic construction kits (Bers, Flannery, Kazakoff, & Sullivan, 2014).

Additional studies were conducted in public school classrooms and summer camp settings on both the TangibleK in general and sequencing specifically (Kazakoff & Bers, 2012; Kazakoff, Sullivan, & Bers, 2013; Sullivan, Kazakoff, & Bers, 2013). The study presented here attempts to control for the confounding variables that arise within a classroom, such as collaboration between children and a lack of individualized assessment opportunities.

Participants in the study attended three 1½-hour sessions in a laboratory setting working one-on-one with a researcher. In addition, each child participated in one initial 1½-hour session in a group of four participants and three researchers. At the completion of the three intervention sessions, the researcher administered post-testing in the same areas as the initial pre-testing. The sessions were planned to be no more than 3 weeks apart in order to decrease any confounds from ongoing development.

One-on-One Sessions

During the one-on-one sessions, lasting approximately 1½ hours each, participants were introduced to the CHERP programming system, tangible and graphical programming blocks, and robotics toolkit (Lego® Mindstorms robots). All sessions were videotaped and audio recorded for further coding. All sessions occurred chronologically and all individual sessions (three per participant) followed the same format: review programming icons, learn new programming icons, complete a challenge activity, answer reflection questions (see Appendix A).

Session overviews: The researcher began each session with a recap of the initial session(s)' robotics and programming activities. The participant then builds his/her own Lego® robot. The researcher then introduces the new programming blocks needed for the sessions' robotic challenge. The participant is provided with all necessary programming blocks and robotic parts needed to complete the challenge, in addition to a poster to remind the participant how to upload a program.

At intervals equal to one-third of the task (approximately 7-10 minutes), the researcher assessed the participant using 5-point Likert Scales to evaluate the participant's understanding of robotics concepts and programming concepts. Three-point Likert Scales were used to assess a participant's level of motivation and engagement. A timeline was used to track the transitions between the tangible-user interface (TUI) and the graphical user interface (GUI).

In order to streamline the scaffolding provided for each participant, for the first third of the task (7-10 minutes), the researcher was only allowed to respond to a participant's questions by mirroring the participant (ex., If the participant asked "how do I put my program on the robot" the researcher would respond "how do you think you would put your program on your robot?"). For the final two-thirds of the task, the researcher was allowed to provide assistance at the participants' level of understanding, not providing them additional information. If, after three iterations, the participant was not able to complete the robotics challenge, the researcher ceased evaluation and assisted the participant in completing the task, in order to ensure the participant had an enjoyable experience and did not become overly frustrated. At the completion of the task, the researcher asked the participant a series of questions to further assess understanding. Data were entered into SPSS for further coding and analysis.

Sequencing assessment: A picture story sequencing assessment adapted from the picture sequencing cards created by Baron-Cohen and colleagues (Baron-Cohen, Leslie, & Frith, 1986) was used as the primary assessment tool in this study. Picture sequencing was chosen as assessment because of the parallels between programming a robot and telling a story (i.e., putting the beginning, middle, and end of a story together). Picture story sequencing assessments are common for assessing sequencing in early childhood (e.g., Brown, 1975; Brown & French, 1976; Linebarger & Piotrowski, 2009; Meadowcroft & Reeves, 1989).

The sequencing assessment used in this study included 15 picture stories, divided into five different categories. Each story contained four picture cards that fit one order to comprise a correct story. The stories of each category were correlated. One story was used from each category for the pre-test and one story from each category was used for the post-test to ensure a test of equal difficulty for both the pre-testing and post-testing tasks. The Baron-Cohen et al. (1986) picture cards were chosen because they were designed for use with preschool and kindergarten children, and they can be used to assess the concept of theory of mind, a direction ultimately not to pursued in this study.

For each picture sequencing trial, the cards were presented according to the standardized procedure. The assessment was standardized using children in a similar age range to the participants in the current study. Baron-Cohen et al. (1986) created this procedure, which corrects for spontaneously placing cards in the correct location (by asking the child to tell the story made by the cards) and ensuring the child understands the pictures presented.

During pre-testing and post-testing, participants were presented with the first picture in the story sequence. The other three pictures were placed in a random order above the first card, facing the participant. The researcher told the participant "this is the first picture (pointing at first card) of the story. Look at the other pictures and see if you can make a story with them." If the participant did not respond right away, the researcher named all the objects in the first picture to make sure the participant understood the drawings. The researcher then asked the participant to continue with the next picture. After all cards were in place, the researcher asked the participant to talk about the story he or she made. The researcher then recorded the order of the cards and the story told. The participant was awarded a score of 2 for a correct sequence, a score of 1 for the correct beginning and ending card, and a score of 0 for a completely incorrect sequence. A participant could earn a total of 10 points on the pre-test and the post-test.

RESULTS

To test if the robotics programming intervention may have had an impact on sequencing ability, picture sequencing pre-test and post-test scores were compared using a paired sample t-test. The mean pre-test score was 7.06 (SD = 2.45) and the mean post-test score was 8.44 (SD = 1.76), a 19.5% increase in average test score. A paired sample t-test found the increase in test scores was significant, $t(33) = 2.71, p < .01$.

Four of the participants had perfect scores on the pre-test and one participant had a 0 on the pre-test and a 10 on the post-test. These participants' scores were checked against coding and data entry errors and verified to be valid representations of the participant's responses. In order to ensure these participants were not skewing the data set as a whole, several combinations of paired-sample t-tests both with and without these participants were run. The results continued to remain significant in all cases, as seen in Table 1.

DISCUSSION

Children who participated in this study were administered the picture sequencing post-test assessment, on average, 17.8 days after the pre-test. The results of the

Table 1. Paired Sample *T*-Test of Sequencing Assessment

Group	*N*	*df*	*t*	*P*	Pre-test Mean *SD*	Post-test Mean *SD*
"Ceiling Effect" Removed	30	29	3.33	< .01**	6.67 ± 2.34	8.43 ± 1.78
"Floor Effect" Removed	32	31	2.29	< .03*	7.50 ± 1.72	8.34 ± 1.77
"Ceiling & Floor Effect" Removed	28	27	3.27	< .01**	7.14 ±1.53	8.32 ± 1.79
All In-Lab Participants	**34**	**33**	**2.71**	**< .01****	**7.06 ± 2.45**	**8.44 ± 1.76**

*Significant at $p < .05$.
**Significant at $p < .01$.

t-test comparing pre-test to post-test scores showed a significant increase. The short duration of time between assessments indicates the increase in score is not likely due to development alone and was impacted by the robotics computer programming intervention. These results support the prediction that young children may improve sequencing skills through learning to program robots with developmentally appropriate tools.

This study used the TangibleK curriculum and CHERP programming language to examine the impact on one skill for early childhood—sequencing. This study indicates that while learning programming in a robotics context, young children also learned sequencing skills, which is a key component of early childhood curriculum. Demonstrating the impact of computer programming on basic story sequencing, in addition to teaching STEM concepts, is a promising step toward integrating robotics programs into early childhood classrooms.

Research on computer programming at an early age was abundant during the prime of Logo, but has been less frequent in the last decade. As focus on innovation and STEM education continues to grow, future research might explore programming languages for early childhood and how these programs may impact a variety of other educational domains and early childhood foundational skills, such as one-to-one correspondence, planning, problem solving, self-regulation, and executive functions.

Limitations

For this study, there was a lack of a large, comparable control group. In order to minimize the confounding variable of development occurring naturally, children were registered for sessions that were no more than 3 weeks between the pre- and post-test. Additional studies within school settings divided children by classrooms in order to have control groups (Kazakoff & Bers, 2012). In the classroom studies, significant differences were found between the intervention and control groups. For the laboratory study, the decision was made to maximize the size of our intervention sample in order to study the possible effects of computer programming on sequencing without the confounding variables of the classroom (e.g., children nested within classroom; collaboration among students).

In addition, the sample is self-selected. Children were recruited via their parents. In order for the child to participate, the parent needed to see the flyer/e-mail, think the child would be interested, and then enroll him or her in the program. This did mean parents had to have an interest in the program and a comfort with research studies including novel technology use. Some parents may have been hesitant to enroll their children in a laboratory study and/or enroll their children in a study that exposed the children to computer programming and robotics.

For interested parents, the study requirement of four sessions of 1½ hours each, combined with the timing of the sessions, may have hindered some parents from enrolling their children in the study. Accommodations were made as best as possible to account for a variety of schedules with session times throughout the day, evenings, and on weekends; though scheduling and time commitment still likely limited the possibility for participation for some interested families. Furthermore, the children needed to be transported to and from a university. The location was accessible by public transportation, but it still may have hindered some participation.

In additional studies, researchers may account for these limitations by going directly to classrooms and having parents opt-out rather than opt-in. This will take away the burden of scheduling, increase the diversity of the population, and eliminate the need for parents to proactively register their children. It also allows children to participate who may not have previously expressed interest in, or have any prior knowledge of computers, technology, and/or robotics. Despite these limitations, the goal of this presented study was to work one-on-one with children to obtain quantifiable examples of learning with robotics that had been seen anecdotally in summer camps and public schools classrooms (Bers & Horn, 2010; Horn et al., 2012). This goal was achieved.

CONCLUSION

This study demonstrates the promise of integrating computer programming into elementary school, especially at young ages. Children in this study, as young as 4½ years old, learned to program a robot in order to complete a variety of challenges and improved his/her score on a sequencing assessment.

This work builds on prior research conducted with young children and computer programming. This current study utilizes a developmentally appropriate programming language and comes at a time when there is increased pressure on children in the United States to increase their knowledge and interest in STEM subject areas, while also living in a time of increasing exposure to digital technologies. There are, of course, still many unanswered questions left to explore: Are the increases temporary or do they impact a child's sequencing skills long-term? Does exposure to computer programming and robotics in early childhood increase interest in STEM subjects? Does exposure to computer programming and robotics in early childhood increase the likelihood of a STEM career choice as an adult?

Though there is still much to learn about the impact of individual digital technologies on the development of young children, the work in this study demonstrates that it is possible to teach young children to program a robot with developmentally appropriate tools, and, in the process, children may not only learn about technology and engineering, but also increased their sequencing abilities, a skill applicable to multiple domains—mathematics, reading, and even basic life tasks. Teaching young children the skills of computer programming using developmentally appropriate tools may be a powerful tool for educating children across multiple domains.

The possibilities and promise for learning from developmentally appropriate digital technologies are seemingly endless, but much research is still yet to be done. Furthermore, the children of today are surrounded by ever-changing digital technologies. Research is essential to understanding the impact of new technologies on the development of children, how children are using these tools, and how they can positively impact child development and education.

APPENDIX A: TangibleK Session Outlines

Session 1. Concepts Introduced:
Robots follow commands; the order of the commands matter

Activities
Learn Icons
Learn How to Upload
Build a Robot
Program Robot to dance the "Hokey Pokey"
Reflection Questions

Session 2. Concepts Introduced:
Repeat, Parameters, and Loops

Activities
Review Icons
Build Robot
Event Travel – Participant programs robot to travel between two spots in the room
Introduce Repeats and Number Parameters
Repeat Travel – Participant programs robot to travel between the same two spots, using fewer blocks (utilizing repeats)
Reflection Questions

Session 3. Concept Introduced: Branches

Activities
Review Icons
Build Robot
Introduce Branch System – The concept of "if/if not"
Branched Travel
Reflection Questions

Post-Testing

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