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The Effect of a Classroom-Based Intensive Robotics and Programming Workshop on Sequencing Ability in Early Childhood

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Abstract This paper examines the impact of programming robots on sequencing ability during a 1-week intensive robotics workshop at an early childhood STEM magnet school in the Harlem area of New York City. Children participated in computer programming activities using a developmentally appropriate tangible programming language CHERP, specifically designed to program a robot's behaviors. The study assessed 27 participants' sequencing skills before and after the programming and robotics curricular intervention using a picture-story sequencing task and compared those skills to a control group. Pre-test and post-test scores were compared using a paired sample *t* test. The group of children who participated in the 1-week robotics and programming workshop experienced significant increases in post-test compared to pre-test sequencing scores.

Keywords Computer programming · Early childhood · Kindergarten · Robotics · Sequencing · STEM

Introduction

Digital technology is everywhere. Children encounter digital technologies daily in their lives that "know" what is going on, such as automatic paper towel dispensers that "know" when hands wave, or cell phones that "know" how to take pictures and play music. Some researchers predict that, due to our rapidly changing technological society, 65 % of the children entering our schools today may have jobs as adults that do not yet exist (Davidson 2011). However, little, if anything, is taught about these technologies in the early childhood classroom (Bers 2008).

That is beginning to change. Understanding an accurate picture of the use of digital devices in the lives of children is essential for those who have an interest in promoting positive child development (Takanishi 2010). Younger children, however, do not provide themselves with the digital media in their lives; parents, families, and schools are the ones to make the purchases or hand the child the tools (Gutnick et al. 2010). A focus around new literacies, such as media literacy, ICT literacy (information and communication technologies), and digital literacy has developed in order to provide frameworks for teaching children about digital media. New media literacies are the social-cultural skills necessary for navigating new media (Jenkins 2006). Information is no longer conveyed just by lines on paper that make up words, we also receive information by images, sounds, and multimedia representations (American Library Association (ALA) 2000; Thoman and Jolls 2003). As a result, the meaning of literacy also changed. Just reading letters on a page is no longer enough to be successful in the twenty-first century; children also need to be fluent in reading, understanding, and communicating with different forms of multimedia (American Library Association (ALA) 2000; Thoman and Jolls 2003).

Section 9.3 of the US Government's National Broadband Plan states that there is no universal definition of digital literacy and the definition is always evolving (FCC 2010). This section of the plan, titled "Addressing Digital Literacy Barriers to Broadband Adoption and Utilization," does note that the meaning of digital literacy varies by age, and that someone in fourth grade does not need the same skills as an adult (FCC 2010), however, the plan summarizes digital literacy as the

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> variety of skills associated with using ICT to find, evaluate, create and communicate information. It is the sum of the technical skills and cognitive skills people employ to use computers to retrieve information, interpret what they find and judge the quality of that information. It also includes the ability to communicate and collaborate using the Internet—through blogs, self-published documents and presentations and collaborative social networking platforms (p. 174).

Despite noting that the same definition does not apply to children and adults, this definition is applicable primarily to adults and older children or adolescents, not to early childhood.

Additional government initiatives and policies are in place to bring STEM (science, technology, engineering, and math education) awareness and education to the earlier grades (see Barron et al. 2011; ISTE 2007; National Association for the Education of Young Children & Fred Rogers Center 2012; U.S. DOE 2010a, b). Many types of digital media foster problem solving and creativity and may be a way to integrate new modes of assessment into classrooms, allowing for more immediate feedback and tailored curriculum (Gee 2008). Some schools, such as the school featured in this study, have redesigned their curriculum to follow the principles of the Engineering Design Process across subjects and daily activities.

This paper will briefly discuss the implementation of a robotics program at a STEM magnet school in the Harlem neighborhood of New York City and present one of the educational outcomes from learning to program robots: learning to sequence. This study grows out of our prior work on the TangibleK project (Bers 2010; Horn et al. 2011) that looked at how robotics and programming can be integrated in developmentally appropriate ways into the early childhood. Previous pilot work showed that the integration of computer programming and robotics in the early childhood classroom may have an impact beyond improving STEM knowledge in the classroom. It may also have an impact on sequencing skills, a traditional area of focus in kindergarten (Kazakoff and Bers 2011).

The central hypothesis of this study is that some of the underling processes involved in programming robots, in particular sequencing of programming commands, are also used when children tell stories in a logical order. Therefore, in the study presented here, we expected an increase in scores between the pre-test and post-test assessment of a picture-story sequencing task. This assessment was conducted before and after children participated in an intervention aimed at building and programming their own robots. The following sections will expand on why we chose to work with robotics, and on how prior research has informed our understanding of robotics, computer programming, and sequencing abilities in early childhood.

Robotics

We focused on robotics as a domain because it is a tool that can help make abstract ideas more concrete, as children can directly view the impact of their programming commands on the robots' actions (Bers 2008). New technologies in general, and robotics in particular, make different kinds of learning opportunities possible, including new ways to foster peer social interactions, and nurture many opportunities for creativity, social, and cognitive development. Educational robotic kits are a new generation of learning manipulatives that also help children develop a stronger understanding of mathematical concepts such as number, size, and shape in much the same way that traditional materials like pattern blocks, beads, and balls do (Brosterman 1997).

Prior research has shown that children as young as 4 years old can build and program simple robots and that there are many benefits to integrating robotic technologies into the early childhood classroom in developmentally appropriate ways (Bers et al. 2002; Bers 2008, 2010; Rogers and Portsmore 2004). Both from an economic and a developmental standpoint, educational interventions that begin in early childhood are associated with lower costs and longer-lasting effects than interventions that begin later in childhood (Reynolds et al. 2011; Cunha and Heckman 2007). In addition, preliminary research suggests that children who are exposed to STEM (Science, Technology, Engineering, and Math) curriculum and computer 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). Robotics was chosen as a gateway to STEM because it integrates all these different disciplines in an applied way.

Computer Programming in Early Childhood Education

Though this study focuses on robotics as a domain, computer programming is the means by which the children program the robots. Computer programming has been called "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). This statement reflects both how powerful—and pertinent—computer programming can be in an early childhood classroom, incorporating creativity and practicing planning, language-building, and problem-solving skills.

Computer programming is also the foundation of all digital technologies and an important skill for twenty-first century literacy (Rushkoff 2010; Jenkins 2006): a skill children will need for most future career and personal pursuits. Programming languages for children, specifically, began to gain popularity when Seymour Papert created Logo and introduced the concept of constructionist programming environments (Papert 1980). Papert's work was largely based Piaget's ideas about children's cognitive development (1970) but applied them to the realm of computer technology (Goldstein and Papert 1977). Piaget was known as the father of constructivism: the idea that interacting with one's environment and constructing an understanding about the world via these interactions leads to knowledge. Papert created his own term, *Constructionism*, to stress the importance of physical constructions in the *digital* world and represent mental thoughts (Papert 1980). 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).

Researchers have continued to build on Logo and Papert's ideas of developmentally appropriate, constructivist programming environments for children. For example, the programming language Scratch, an graphical programming language, allows young children (8 years of age and older) to build and share their own stories, games, and artistic creations (http://scratch.mit.edu; Brennan et al. 2010; Maloney et al. 2008). Other graphical programming languages, such as Kodu (http://fuse.microsoft.com/page/kodu), Etoys (http://www.squeakland.org/), and Storytelling Alice (http://www.alice.org/kelleher/storytelling/index.html), bring the concepts of computer programming to young people in more accessible ways; however, they are, like Scratch, designed for children in middle-to-later elementary school grades and above (Resnick et al. 2009a, b).

There are a few combination computer programming and robotics tools designed for younger children in educational settings. Popular examples include, LEGO® WeDo™ (http://www.legoeducation.us/eng/categories/products/elementary/lego-education-wedo) and Bee-Bot (http://www.terrapinlogo.com/bee-botmain.php). These two tools both have some limitations for this study, however, as Lego We-Do is marketed for ages 7+ and Bee-Bot, has limited commands.

In addition, tools such as Little Bits (http://littlebits.cc/) and Pico Cricket (http://picocricket.com/aboutpico.html) mesh motors, wires, circuits and creative materials, but are also designed for children ages 8 and above.

CHERP, designed for kindergarten-aged children, is a graphical-tangible hybrid programming language, meaning, the child is allowed to transition back and forth between the screen-based (graphical) and tangible (physical, wooden, block-based) programming interfaces for robots (Bers 2010; Horn et al. 2011). CHERP software may be used with Lego Mindstorms robotics kits, LEGO® WeDo™ robotics kits, and custom designed robotics kits; blended with arts and crafts materials.

A review of earlier work in this emergent field suggests children who participate in computer programming typically score around 16 points higher on various cognitive-ability assessments than children who do not participate (Liao and Bright 1991). A large scale study of children using the Logo programming language, (Clements et al. 2001) demonstrated that children in grades K − 6 scored significantly higher on tests of mathematics, reasoning, and problem-solving. Children who used Logo in kindergarten were also found to have sustained attention, self-direction, and took pleasure in discovery (Clements 1987). New research on innovative programming environments support the argument that children's programming of animations, graphical models, games, and robots with age-appropriate materials allows them to learn and apply core computational thinking concepts such as abstraction, automation, analysis, decomposition, modularization, and iterative design (e.g. Bers and Horn 2010; Mioduser et al. 2009; Mioduser and Levy 2010; Resnick 2006; Resnick et al. 2009a, b).

Computer programming is defined as "using…sequence of instructions, variables, recursion, etc. to write solutions to problems… (Liao and Bright 1991, p. 253)." Since sequencing is at the core of one's ability to understand and create computer programs (Pea and Kurland 1984) and computer programming has been linked to improvement in cognitive skills (Clements 1999; Liao and Bright 1991), we sought through this study to continue our exploration of the relationship between computer programming and sequencing in the early childhood classroom.

Sequencing

Sequencing is an important skill for early childhood found in both curricular frameworks and learning assessments. Sequencing is a component of planning and involves putting objects or actions in the correct order (Zelazo et al. 1997). For example, retelling a story in a logical sequence, ordering numbers in the correct sequence, and understanding the sequence of a day's activities are all sequencing activities represented in curriculum frameworks for children in kindergarten in both language arts and mathematics (Massachusetts Department of Elementary and Secondary Education 2008). Sequencing, along with sorting, measurement, and pattern recognition are a child's *mathematical building blocks*; starting with these foundational skills, children being to think of the world mathematically (Sarama and Clements 2003).

The Early Childhood Longitudinal Study (US Department of Education, National Center for Education Statistics 2001) was conducted in 1998 to collect baseline data on

19,000 kindergarten students. The ECLS included “recognizing a sequence of patterns” as a mathematics assessment measure (US Department of Education, National Center for Education Statistics 2001). This study found 58 % of kindergarteners are proficient in recognizing patterns of sequence, and 20 % are proficient in ordinal sequencing, with the older children more likely to achieve these skills than the younger children (US Department of Education, National Center for Education Statistics 2001). Ordinal sequencing, recognizing first, second, third, etc. is key to sequencing a story or series of daily activities.

Historically, Piaget believed children in the preoperational stage might not be able sequence, due to their inability to reason about more than one object or action at a time. He believed the ability to reason about multiple objects simultaneously, and thus be able to reverse them, was key to understanding sequencing (Piaget 1969). In his studies, Piaget found children younger than six or seven were unable to successfully complete a story sequencing task (Piaget 1969). Since then, however, studies have been conducted that show that children as young as two can begin to understand, and imitate, short (2–3 action), highly familiar sequences (O’Connell and Gerard 1985). Other studies found children in kindergarten can construct sequences, but not necessarily discuss logic or cause and effect related to those sequenced stories (Brown and French 1976).

Overall, research has shown that children in the preoperational period may be able to sequence in a forward direction without the need to understand reversibility (Fivush and Mandler 1985). The kindergarten child has the easiest time with a familiar sequence in the forward order, but a more difficult time, even in the forward order, for events the child has not experienced. The child, in this case, would have to rely on understanding and inferring logical connections between events, rather than his/her own experiences, which is difficult for the young child in the preoperational period (Fivush and Mandler 1985; Brown and French 1976).

Since sequencing is an important component of both early mathematics and early literacy learning, it is a common theme in early childhood classrooms. The use of sequences common in kindergarten are the ones we chose to focus on in this study and assess with a picture story assessment. Story sequencing skills, along with vocabulary knowledge and story comprehension in kindergarten, are strongly linked to success in literacy later in life (Snow et al. 1994). Using pictorial stories is common in early childhood because they require narrative thinking and understanding of sequences without relying on words (Paris and Paris 2003).

Computer programming can be seen as a version of story sequencing. Computer programming, at its core, is the use of symbolic commands arranged in an appropriate sequence to create a series of actions in order to instruct a computer’s behavior (Pea and Kurland 1984). In order to create a successful program, children must use procedural thinking and understand the logic of instructions. When creating a program, children are thinking in terms of *next*, *before*, and *until* which are all components of sequencing (Pea and Kurland 1984).

We set out to test the hypothesis that children who engage in programming activities increase their story sequencing skills. In the study described in this paper, we predicted that young children who program robots with a developmentally-appropriate computer programming interface would increase in post-test picture story sequencing scores compared to their baseline pretest scores. In prior studies (Kazakoff and Bers 2011; Kazakoff and Bers, in press) we found children did increase their average pre-test sequencing scores, compared to post-test sequencing scores, in both laboratory and classroom studies.

In our laboratory study, sequencing scores significantly increased from 7.06 to an average 8.44 post-test sequencing score over the course of 2–3 weeks (average 17.8 days). These students worked one-on-one with a researcher who was very familiar with the technology (Kazakoff and Bers 2011). In another study we found kindergarten students working with their classroom teacher teaching the curriculum in full-size classrooms, increased their sequencing scores over a period of several months. A $2 \times 2 \times 2$ ANOVA was run for the four classrooms involved in the study. A significant effect was found between Test Score (Pre vs. Post) and Group Assignment (Experimental vs. Control), $F(1,50) = 5.642$, $p < .02$, meaning there was a relationship between the change in Pre-Test and Post-Test scores and whether the participant was assigned to the experimental or control group (Kazakoff and Bers, in press). The interaction effect for Test Score and School Assignment was not significant, meaning there was not a significant interaction between the classroom the participant was enrolled in and their Pre-Test and Post-Test scores.

For the current study, we focused on pre-kindergarten and kindergarten students, in classroom settings, over 1 week to see if programming in a robotics context would, again, improve sequencing scores.

Method

Participants

Participants in this study attended a public, early childhood magnet school in the Harlem area of New York City. This school serves 240 children in Pre-K through 2nd grade and specializes in leveraging the learning strengths of young children through an engineering design approach. The school received magnet status on October 1st, 2010, and the 2010–2011 school year marked the first year it began to implement a focus on engineering. The 2011–2012 school year was the first year that the administration set a goal of goal of 10 hours a week of engineering instruction in all classrooms. As a part of this new focus, all grades are now introduced to a building, design, and robotics curriculum.

Prior to 2011–2012, the school was performing sub-par according to NYC School Progress Reports. For the 2009–2010 school year, they received an F rating for both Student Progress and Student Performance and a C rating overall. As of the 2010–2011 school year, the school's overall grade was still a C. The participants in this study included 13 pre-kindergarten students and 16 kindergarten students. These students are identified by parents/guardians as 41.8 % African American, 25.4 % Hispanic, 1.5 % Caucasian, and 7.5 % multi-racial. About 80 % of the participating students speak English (or a combination of English and Spanish) as their primary language; however, no participants were classified by their parent/guardian as English Language Learners. Spanish was spoken as a secondary home language by 17.1 % of the children. For the pre-kindergarten group included in data analysis, 46 % were male and 54 % were female. For the kindergarten group included in data analysis, 36 % were male and 64 % were female.

A control group was also assessed. The control group students were part of a small, university-affiliated child care center outside of Boston, MA. This control group received the pre-test followed by the post-test assessment after 9 days, with no robotics intervention during those 9 days. The control group was comprised of 13 children. These 13 children were 62 % male and 38 % female with an average age of 4.77 years, SD = .59. Children from the control group participated in a robotics and programming activities after the conclusion of the second sequencing assessment.

Procedure

Children who participated in this study were pre-tested using a standardized sequencing assessment before their participation in the 1-week robotics curriculum. On the last day of robotics week, the children were post-tested using another form of the standardized sequencing assessment.

Sequencing Assessment

Children were assessed using a picture-sequencing task. Picture story sequencing assessments are common educational tools and assessment measures in early childhood classrooms (e.g. Linebarger and Piotrowski 2009; Meadowcroft and Reeves 1989; Brown and French 1976; Brown and Murphy 1975). A picture sequencing assessment was chosen based on the similarities between programming a robot and telling a story that involves ordered steps (i.e. putting the beginning, middle, and end of a story together vs. putting together the beginning, middle, and end of a sequencing of code).

The sequencing assessment used in this study was derived from the picture sequencing cards created by Baron-Cohen et al. (1986). Baron-Cohen et al., created a battery of 15 picture stories, containing four cards per story. We choose this particular set of picture cards because it was designed for use with preschool and kindergarten. The stories are broken down into five different categories and stories of each category are correlated. The five categories are: mechanical 1 (an action with an object), mechanical 2 (an action with a person and an object), behavioral 1 (routines involving the self), behavioral 2 (social routines involving others), and intentional (theory of mind). Upon using Baron-Cohen's cards in prior studies, we began to notice some of the images were quite dated (see Baron-Cohen et al. 1986) in terms of color, design, and universality of characters. For the purposes of this study, we created our own cards based on Baron-Cohen's designs (see "Appendix A"). Parallel-form correlation was assessed between the Baron-Cohen cards and the new redrawn cards and yielded a significant and strong correlation, $r(56) = 0.70, p < .001$.

One picture story from each category for the pre-test and one picture story from each category for the post-test was used to ensure a test of equal difficulty for both the pre-testing and post-testing tasks. 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 the testing procedure which corrects for spontaneously placing cards in the correct location and ensuring the child understands the pictures presented.

During both 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. All cards were placed on the table facing the participant. The participant was told "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 "tell me about the story you made" and recorded the participant's response. A score of 2 was awarded for a correct sequence, a score of 1 was awarded for the correct beginning and ending card, and a score of 0 was used for an incorrect sequence. For both the pre-testing and post-testing a participant could earn a total of 10 points.

Robotics Week Curriculum Overview

During robotics week children used LEGO® Education WeDo™ *Robotics Construction Sets*, with the CHERP hybrid tangible-graphical software, and a variety of art

Fig. 1 CHERP Tangible-Graphical interface. This figure illustrates the components of the tangible-graphical computer programming interface used in this study. Children use the tangible blocks (pictured on the *left*) or the blocks on the computer screen (*center*) to program the robot (pictured on the *right*)

materials to build and program their robots. At the end of the week the school held an Open House for parents, siblings, and friends to see the final robotic creations. Although all of the classrooms followed a curriculum focused on the engineering design process, each grade had a culminating theme that was integrated with a greater unit teachers were covering in their classrooms. The Pre-K students' final theme was "Robot Recyclers". After learning about the recycling process and different tools for recycling, the children built and programmed robotic vehicles to carry, push, and sort recyclable materials found in the classroom. The Kindergarten students' culminating theme was "Chorebots," a continuation of their unit on household tools. They designed, built, and programmed robots to help complete a household a chore.

Programming Software

CHERP is a hybrid tangible and graphical computer language designed to provide young children with an engaging introduction to computer programming. CHERP allows children to create both physical/tangible and graphical/on-screen programs to control their robots (Bers 2010; Horn et al. 2011). Children can create physical programs using interlocking wooden blocks or onscreen programs using the same icons that represent actions for their robots to perform (See Fig. 1). With CHERP there is no such thing as a syntax error. The shape of the interlocking blocks and icons creates a physical syntax that prevents the creation of invalid programs. CHERP programs can be compiled quickly from the tangible or graphical blocks with a simple mouse click (Bers 2010; Horn et al. 2011).

CHERP uses a collection of image-processing techniques to convert physical programs into digital instructions. Each block in the language is imprinted with a circular symbol called a "TopCode" (http://users.eecs.northwestern.edu/~mhorn/topcodes/). These codes allow the position, orientation, size, shape, and type of each statement to be quickly determined from a digital image. A standard webcam can be connected to a desktop or laptop computer to take a picture of the program, or, a laptop's internal webcam can be used. A compiler converts the picture into digital code that is downloaded and transmitted to the WeDo™ robot through the LEGO® WeDo™ USB hub.

Robotics Hardware

The LEGO® Education WeDo™ *Robotics Construction Set* is a robotics kit that allows children to build LEGO® robots that feature working motors and sensors. The construction sets contain more than 150 elements including a motor, tilt sensor, motion sensor, a LEGO® *USB* hub, gears, and a variety of LEGO® bricks. Students also used

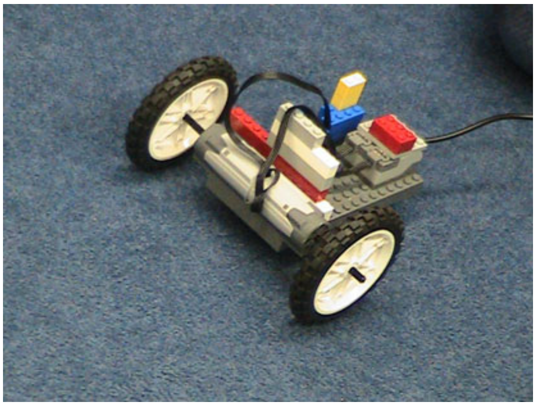

Fig. 2 LEGO® WeDo™ robot. An example of a LEGO® WeDo™ robot constructed by a child during this study

LEGO® wheels (not included in the kit) to build their robots (See Fig. 2 above).

Once a robot is built, programs can be uploaded to it by placing the program in the web camera's field of view, and connecting the robot to the computer using the USB hub. The computer takes a photo to "see" the blocks, and then the program is visible on-screen and is sent to the robot. To upload from the graphical icons onscreen, children click and drag the programming icons together. Like the tangible blocks, they will only "snap together" when they are close enough and can make a logical sequence.

Results

Sequencing card pre-testing scores were compared to post-testing scores for both the pre-kindergarten and kindergarten groups using a paired sample *t* tests. The kindergarten students' pre-test average score was 6.43 and post-test average score was 8.79, an increase of 2.36 points. This difference was significant, $t(13) = 4.84$, $p < .001$. The pre-kindergarten students' pre-test score average was a 3.77 and post-test score average was a 4.85, a difference of 1.08 points. This difference is significant,[1] $t(12)$, $t = 1.82$, $p < .05$.

To control for growth in sequencing ability or a novelty effect based on the cards themselves, we assessed a control group of 13 children over the course of 9 days. The post-test was given 9 days after the pre-test to student who had not had the robotics intervention, slightly more than the amount of time between the pre and post tests of the children in the experimental group which participated in the robotics week. The control group pre-test average score was 6.07 and post-test average score was 6.36. The difference was not significant, $t(13) = 0.291$, $p = .78$ (two-tailed); $p = .39$ (one-tailed).

[1] Based on prior studies, we predicted the direction of the results and, therefore, used a one-tailed significance value.

Discussion

These results show a significant, positive impact on sequencing scores with just 1 week of working with robotics and programming in a pre-kindergarten and kindergarten classroom. Not only does the study show an increase in sequencing scores in this school, it replicates the results of prior studies in a new classroom context with new teachers. These findings expand on our previous research that showed children increased their pre-test to post-test sequencing scores in a classroom setting over a period of several months after being exposed to a programming and robotics educational program. Furthermore, the research presented in this study indicates that it might be possible to see an increase in sequencing ability in as little as a single week. However, this was an intense period of work with robotics and programming, and it was in a school with an engineering design focus. These findings may have implications for how to design the integration of robotics and computer programming in early child curricula.

Limitations

This study has limitations in regard to the sample size. Several parents opted their children out of our research study and/or did not return permission slips despite several attempts at collection, therefore, we were unable to collect or use data on those children for this paper. In addition, due to the nature of the work within the classroom, we were allotted limited time to collect pre-test and post-test assessments. If a child was absent during pre- and/or post-testing time, he or she could not be included in analysis.

Future Directions

Going forward, we will continue to replicate our studies using sequencing assessments in early childhood classrooms to explore how programming in a robotics context may impact, or be impacted by, sequencing ability across a variety of classroom types, locations, and durations of projects. We will also explore sequencing with programming tools outside of the robotics domain. Additionally, we would like to explore how programming in a robotics context might influence a child's performance in various early childhood curricular areas that require sequential thinking. For example, we will seek to answer questions such as: do programming tasks impact a child's performance on number sequencing and literacy assessments as well? Finally, a longitudinal study to see if the sequencing effects persist would be a great contribution to this body of work.

Conclusion

Sequencing is an important component of both early mathematics and early literacy learning and is therefore of particular importance in early childhood classrooms. Results from this study seem to indicate that it is possible to see increases in the sequencing ability of pre-kindergarten and kindergarten students participating in a robotics and programming curriculum in as little as 1 week, as long as the week is intense (at least 10 hours of robotics and programming work). We hypothesize this may be because the same cognitive structures involved in programming robots with a particular sequence of programming commands, are also used when children tell stories in a sequential order.

Robotics offers children and teachers a new and exciting way to tangibly interact with traditional early childhood curricular themes. Though there is still much to learn about the impact of individual digital technologies on the development of young children, our work 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 increase their sequencing abilities, a skill applicable to multiple domains—mathematics, reading, and even basic life tasks. Teaching young children about and through computer programming and robotics using developmentally appropriate approaches may be a powerful tool for educating children across multiple domains.

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Appendix A: Sample Sequencing Cards

See Figs. 3 and 4.

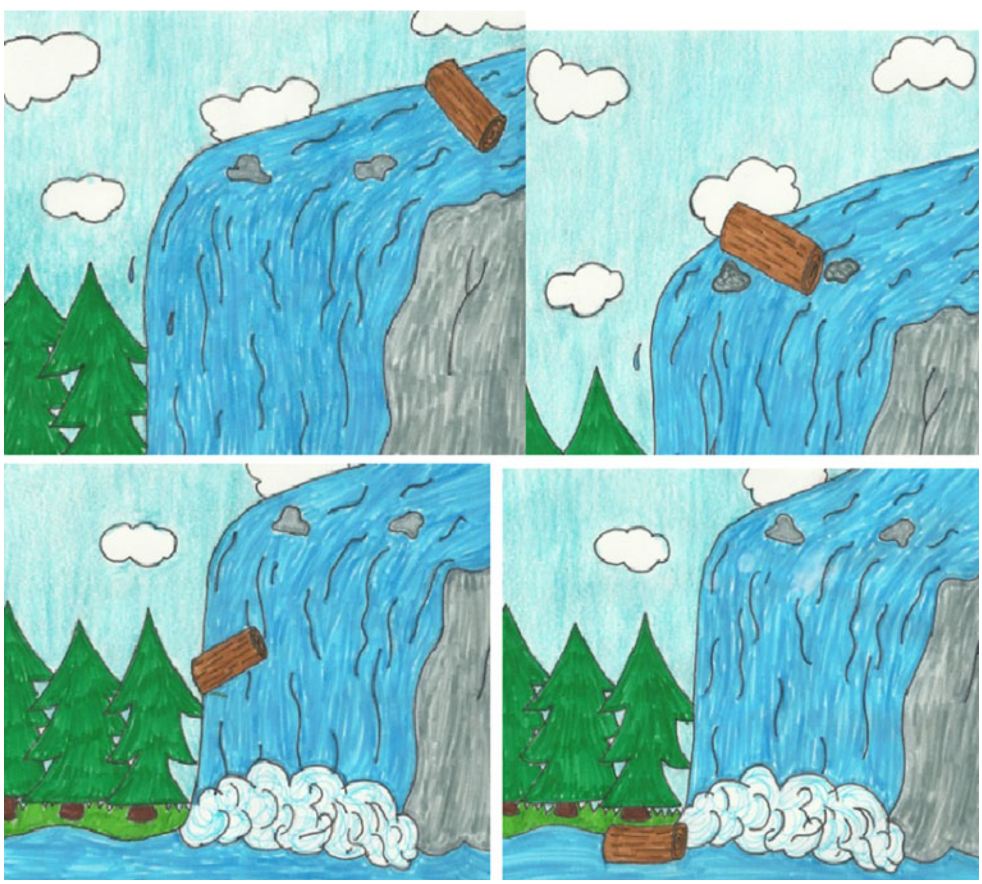

Fig. 3 Example of Mechanical 1-type sequencing story cards. This figure illustrates one of the examples of the story sequencing card sets used in this study

Fig. 4 Example of Intentional-type sequencing story cards. This figure illustrates one of the examples of a story sequencing card sets used in this study

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