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Computational thinking and tinkering: Exploration of an early childhood robotics curriculum

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ABSTRACT

By engaging in construction-based robotics activities, children as young as four can play to learn a range of concepts. The TangibleK Robotics Program paired developmentally appropriate computer programming and robotics tools with a constructionist curriculum designed to engage kindergarten children in learning computational thinking, robotics, programming, and problem-solving. This paper documents three kindergarten classrooms' exposure to computer programming concepts and explores learning outcomes. Results point to strengths of the curriculum and areas where further redesign of the curriculum and technologies would be appropriate. Overall, the study demonstrates that kindergartners were both interested in and able to learn many aspects of robotics, programming, and computational thinking with the TangibleK curriculum design.

1. Introduction

For decades, early childhood (preschool to grade two) curricula have focused primarily on literacy and math, especially with the educational reforms of No Child Left Behind (Zigler & Bishop-Josef, 2006). However, there has been some recent attention to science, technology, engineering, and math (STEM) learning for young children (Gelman & Brenneman, 2004; Sesame Workshop, 2009; White House, 2011). Furthermore, new technology learning standards and best practices for integrating technology into early childhood education have been developed (Barron et al., 2011; International Society for Technology in Education (ISTE), 2007; NAEYC & Fred Rogers Center for Early Learning and Children's Media, 2012; U.S. Department of Education, 2010). Of note, the technology policy statement from NAEYC & Fred Rogers Center for Early Learning and Children's Media (2012) provides a guide for early childhood education professionals in using interactive digital technologies in balanced and developmentally appropriate ways. It addresses important issues related to using digital technology with children ages three–eight years, including the needs for technology use to serve the needs of the children, and for educators to be able to understand, evaluate, and integrate developmentally appropriate technologies in their classrooms. However, there is little research on computer programming specifically for early childhood, the subject this paper explores.

As new devices, from smartphones and tablet computers to electronic learning toys, find new audiences with increasingly young children, challenging question arise about how to define developmentally appropriate activities and content for children of different ages. While the majority of research on robotics and programming in education focuses on later schooling, teaching these subjects during foundational early childhood years can be an engaging and rewarding experience for young learners (Bers, 2008). Previous research has shown that children as young as four–six years old can build and program simple robotics projects (Bers, Ponte, Juelich, Viera, & Schenker, 2002, pp. 123–145; Cejka, Rogers, & Portsmore, 2006; Kazakoff, Sullivan, & Bers, 2012; Perlman, 1976, p. 260; Wyeth, 2008) as well as learn powerful ideas from engineering, technology, and computer programming while also building their computational thinking skills (Bers, 2008). Robotic manipulatives allow children to develop fine-motor skills and hand–eye coordination while also engaging in collaboration and teamwork. Additionally, robotics can provide a fun and playful way for teachers to integrate academic content with the creation of

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meaningful projects. Through robotics, young children can experiment with concepts of engineering as well as storytelling by creating narrative contexts for their projects (Bers, 2008). By engaging in these types of robotics projects, young children play to learn while learning to play in a creative context (Resnick, 2003).

Computers offer new ways of representing and interacting with information and an entirely new category of "objects to think with" (Papert, 1980). In the form of programmable and interactive robots, computers can become powerful learning tools. Robotics offers children the opportunity to engage with content from the domain of computer science, practice problem-solving skills, and work on fine-motor skills and eye–hand coordination. The TangibleK Robotics Program, a design-based research initiative now in its fifth year, has paired developmentally appropriate programming and robotics tools with a curriculum to engage kindergartners in learning computational thinking, robotics and programming concepts, as well as problem-solving and reasoning. The goal of this paper is to present young children's learning outcomes on computer programming concepts as taught through the TangibleK curriculum in order to highlight the potential for learning of integrating computer programming and robotics into the early childhood classroom.

1.1. Theoretical framework: constructionism and positive technological development

The theoretical approach used for designing the educational intervention and curriculum and for integrating the TangibleK Robotics Program into early childhood classrooms incorporates elements from Papert's (1980) constructionist framework, which states that children can learn deeply when they build their own meaningful projects in a community of learners and reflect carefully on the process.

Papert's (1980) *constructionism* is rooted in Piaget's (1954) *constructivism* – which conveys the idea that the child actively builds knowledge through experience – and the related "learn-by-doing" approach to education. While Piaget's (1954) theory was developed to explain how knowledge is constructed in an individual's mind, Papert (1980) expands on it to focus on the ways that internal constructions are supported by constructions in the world, including through the use of computers and robotics. A constructionist teaching approach provides children the freedom to explore their own interests through technologies (Bers, 2008) while investigating domain-specific content learning and also exercising meta-cognitive, problem-solving, and reasoning skills (e.g., Clements & Gullo, 1984; Clements & Meredith, 1992). Papert (1980) discussed that well-designed constructionist activities have embedded in them 'powerful ideas', central concepts within a domain that are both epistemological and personally useful, interconnected with other disciplines, and have roots in intuitive knowledge that a child has internalized over a long period of time (Bers et al., 2002; Papert, 1980). An idea may be considered powerful to the degree that it is useful in building and extending further knowledge (Papert, 2000). The robotics curriculum described in this paper is composed of powerful ideas from the domains of computer science and engineering (e.g., the engineering design process, debugging, robotic motion and sensing, using programming instructions, control flow by sequence, control flow by specific instructions).

Classroom activities designed to impact learning outcomes and cognitive growth, also have an impact on (and are influenced by) children's social, emotional, and moral development. As a framework to guide the design and implementation of a robotics curriculum that also focuses on these dimensions of the child, Bers' (2010, 2012) Positive Technological Development (PTD) was utilized. PTD takes into consideration the learning environment and pedagogical practices, as well as cultural values and rituals, which mediate teaching and learning (Bers, 2008; Rogoff, Goodman Turkanis, & Bartlett, 2001). The educational experience proposed by the presented robotics curriculum was structured using the PTD framework to encourage six behaviors, which in turn foster the development of beneficial core cognitive and social traits. Specifically, engaging in content generation, creative design and problem-solving, collaboration, communication, choices of conduct, and community-building may lead to a sense of competence and confidence, the ability to connect with and care about others, contribution to entities outside the self, and moral character (Bers, 2010, 2012). For instance, by iteratively planning and revising a robotics project in a supportive environment, children may gain confidence in their abilities to learn and solve problems. Alternatively, discussions of how to share limited resources fairly amongst the class are opportunities for positive moral development.

1.2. Learning through computer programming

Embedded in the exploration of computer programming and robotics, the TangibleK curriculum also fosters *computational thinking*. This term has been defined in many ways and encompasses a broad and somewhat debated range of analytic and problem-solving skills, dispositions, habits, and approaches used in computer science (Barr & Stephenson, 2011; International Society for Technology Education and The Computer Science Teachers Association, 2011; Lee et al., 2011). The TangibleK curriculum specifically fosters computational thinking skills such as: problem representation; systematicity in generating and implementing solutions; exploring multiple possible solutions; problem-solving on multiple levels – from approaching the overall challenge to "debugging" or trouble-shooting specific difficulties with a given solution's implementation; productive attitudes toward "failure" and misconceptions uncovered along the route to a successful project; and strategies for approaching open-ended and often difficult problems. Such skills are of general applicability beyond robotics and computational thinking.

1.3. The TangibleK Robotics Program

The TangibleK Robotics Program, whose design is informed by the theoretical frameworks of constructionism and PTD, has iteratively implemented and assessed a set of programming and robotics tools, curricula, and pedagogical approaches in close collaboration with hundreds of children and dozens of teachers over the course of five years. The research goals of the TangibleK Robotics Program are to:

1) Provide an evidence-based description of young children's learning trajectories in computational thinking and capacity to understanding computer programming and robotics concepts when given developmentally appropriate materials,
2) Develop and test an early childhood curriculum to teach developmentally appropriate concepts from computer programming and robotics to children in kindergarten through second grade,
3) Investigate the design features of the programming interface and the mediating role interface design plays in learning to program.