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Gender differences in kindergarteners' robotics and programming achievement

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Abstract Early childhood is a critical period for introducing girls to traditionally masculine fields of science and technology before more extreme gender stereotypes surface in later years. This study looks at the TangibleK Robotics Program in order to determine whether kindergarten boys and girls were equally successful in a series of building and programming tasks. The TangibleK Program consisted of a six lesson robotics and programming curriculum that was implemented in three different kindergarten classrooms (N = 53 students). Although previous research has found that males outperform females in robotics and programming related fields, it was hypothesized that the young age of participants and their limited cultural indoctrination regarding gender stereotypes would allow boys and girls to have equal success in this program. Although boys had a higher mean score than girls on more than half of the tasks, very few of these differences were statistically significant. Boys scored significantly higher than girls only in two areas: properly attaching robotic materials, and programming using Ifs. Overall, both boys and girls were able to successfully complete the program.

Keywords Early childhood · Gender differences · Stereotypes · Robotics · Computer programming-Powerful ideas · STEM fields

Introduction

Men continue to outnumber women in numerous STEM (science, technology, engineering, mathematics) fields including computer science, mathematical science, environmental science, and electrical engineering (AAUW 2010). This persistent gender disparity may be due to the negative effect of stereotype threat on women's confidence and interest in these traditionally masculine fields (Spencer et al. 1998). One way to address this gender

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disparity is to attract the interest of girls during formative early childhood before extreme gender stereotypes are ingrained (Metz 2007; Steele 1997).

This paper presents research from the NSF-funded TangibleK Robotics Program, a classroom-based study carried out in three kindergarten classrooms in the greater Boston area (Bers 2010). 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 of both genders (Bers 2008). Previous research has shown that children as young as 4 years old can build and program simple robotics projects (Bers et al. 2002; Cejka et al. 2006; Perlman 1976). Robotic manipulatives allow children to develop fine motor skills and hand-eye coordination while also engaging in collaboration and teamwork. They also provide a concrete and tangible way to understand abstract ideas (Bers 2008). Results from research on the TangibleK Robotics Program demonstrate that kindergarteners can successfully learn powerful ideas of engineering, technology, and computer programming while also building their computational thinking skills (Bers 2010). Introducing robotics and programming in early childhood also serves as a way to increase girls' interest and abilities in engineering fields before stereotype threat makes this more difficult in later years. The purpose of this study was to analyze results from the TangibleK Program in order to determine whether boys and girls were equally successful in their mastery of introductory robotics and programming.

Literature review

Gender disparities in STEM fields

"STEM" has been defined in a variety of ways in past research (AAUW 2010). For the purposes of this paper, the term is used to refer to the physical, biological, and agricultural sciences; computer and information sciences; engineering and engineering technologies; and mathematics. While the gender disparity between women and men in these fields has noticeably decreased over the past decade, there are still several noticeable gaps that persist (AAUW 2010). In some fields, like Computer Science, female participation has been on a steady decline during the past decade (National Center for Women and Technology 2011). In 2009, only 11 % of undergraduate Computer Science degrees from major research universities were granted to women and, between the years 2000–2009, there has been a 79 % decline in first year undergraduate women interested in pursuing Computer Science (National Center for Women and Technology 2011). This may be because in high school, girls are less likely than boys to take college preparatory science and math Advanced Placement Exams including: Calculus, Computer Science, and Statistics (AAUW 2010). In the professional arena, women make up less than 30 % of environmental scientists, less than 30 % of computer scientists, less than 10 % of electrical engineers, and less than 7 % of mechanical engineers (AAUW 2010).

Very little research specifically exploring gender differences in young children's robotics and programming abilities exists- most likely because use of robotics and programming in early childhood classrooms is still very new. However, research on adolescents and adults has shown some gender differences. Nourbakhsh et al. (2004) looked at gender differences over a 7 week robotics course for high school students. The authors found that girls were more likely to have struggled with programming than boys and that girls entered the course with less confidence than boys. However, it was also found that by the end of the course girls' confidence increased more than the boys' did (Nourbakhsh et al. 2004). Similarly, Milto et al. (2002) found that although men and women in an introductory engineering class displayed equivalent competency in robotics activities, men were more confident in their abilities than women.

Stereotype threat

Why is it that men seem to have more confidence than women in so many STEM fields? The answer may lie in the negative effect of stereotype threat on women's confidence and interest in these traditionally masculine areas. *Stereotype threat* refers to the anxiety that one's performance on a task or activity will be seen through the lens of a negative stereotype (Steele 1997; Spencer et al. 1998). For example, Spencer et al. (1998) found that women experience stereotype threat in the domain of math. In this study, when women were shown gender differences on a math test (to induce stereotype threat) before being asked to complete it, they performed significantly worse than their male counterparts. When stereotype threat was avoided (by telling participants that there were no gender differences associated with the test) women and men performed similarly. Stereotype threat is not only triggered by explicit statements. Environmental and situational factors can also trigger a negative stereotype (Shapiro and Williams 2011).

One way to avoid long-lasting negative stereotypes is to introduce science, technology, engineering, and mathematics concepts at a very early age. Research suggests that children who are exposed to STEM 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). Thus, the TangibleK Program hoped to attract the interest of both boys and girls at an early age in order to prevent students from acting on negative stereotypes later in life.

The purpose of this study was to determine whether introducing robotics and programming during kindergarten allows both boys and girls to excel in the traditionally masculine areas of robotics and programming.

Method

Three kindergarten teachers implemented the TangibleK curriculum in their classrooms, after receiving training. Training was 3 h long and consisted of working with a research assistant to learn how to use the programming language and robotics kits, and completing each of the curriculum activities. Each teacher received technical and assessment support in their classrooms from research assistants while teaching.

During each lesson in the curriculum, children were assessed by their classroom teachers or a research assistant. In order to ensure all assessments were conducted as close to identically as possible, research assistants and teachers were both trained on administering the assessment tools prior to implementation of the study and no other adults were asked to assess the children. Because TangibleK is a unique early childhood curriculum, no comparable assessment tools are yet in existence. Therefore, it was necessary to create new assessments for the purposes of this study. Based on the data collected from assessments, classroom observations, interviews with students and teachers, and analysis of student work, the assessment tools developed for TangibleK were refined several times to increase the face validity of the measurements based on teacher and researcher feedback. Outside consultants were also asked to evaluate and improve the measurements.

In addition to taking notes on children's key understandings and misconceptions, children were also each assessed in small groups (approximately 4 children) on each child's achievement of the core goals of the activity. Children's learning achievement was determined based on conversation with the child during the activity, interview questions, looking at what they built, and looking at the programs they created. Children were assessed on the thoroughness of their understanding and application of core concepts and skills in each lesson using the TangibleK assessment form, a 6-point Likert scale, as follows:

5—Complete achievement of the goal, task, or understanding;
4—Mostly complete achievement of the goal, task, or understanding;
3—Partially complete achievement of the goal, task, or understanding;
2—Very incomplete achievement of the goal, task, or understanding;
1—Did not complete the goal, task, or understanding;
0—Did not attempt task/Other.

Debugging, or problem solving, is a critical element of the Engineering Design Process that was also assessed using the same Likert scale described above. Children were assessed on four debugging skills in every lesson: (1) recognizing that something is not working, (2) keeping the original goal or changing to an appropriate alternative, (3) having a hypothesis as to the cause of the problem, and (4) attempting to solve the problem.

To keep assessment manageable in a busy classroom and also give children a tool to self-regulate their exploration process and self-assess, the assessment criteria given with each lesson can also constitute a sequence of concrete achievements leading up to an "Engineer's License." Each lesson is associated with a different license level, e.g. "Sturdy Builder" or "Programmer I," that incrementally completes the license, at which point the child is ready to start a final project. During the course of each lesson, children explore and learn at different rates. When they think they have accomplished the criteria for that lesson's assessments, they demonstrate this to a teacher or research assistant, who marks that licensure level on their Engineer's License and also on the Likert scales described above.

Sample

Participants in this study come from three different classrooms within two different schools in greater Boston area. Participants from Classroom 1 come from an independent, K-8, religious-based, private school in a suburb of Boston. Participants from Classrooms 2 and 3 come from the same public, K-8 school (NCLB Level 3) located just outside of Boston. A total of N = 53 students was included in analysis (28 males and 25 females).

The robotics program

Participants used the CHERP (Creative Hybrid Environment for Robotic Programming) program, the LEGO® brick from the LEGO® MINDSTORMS™ kit, and a variety of art materials to build and program their robots.

Programming software

CHERP, designed for the TangibleK Robotics Program, is a hybrid tangible/graphical computer language designed to provide young children with an engaging introduction to computer programming. CHERP allows users to create both physical and graphical programs to control their robots (Bers and Horn 2010). Children can create physical programs using interlocking wooden blocks, or onscreen programs using the same icons that represent actions for your robot 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 in a matter of seconds with the press of a button (Bers and Horn 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 (Horn et al. 2009). These codes allow the position, orientation, size, shape, and type of each statement to be quickly determined from a digital image. A standard webcam connected to a desktop or laptop computer takes a picture of the program. A compiler converts the picture into digital code that is downloaded and transmitted to the robot with an IR tower in a matter of seconds (Bers and Horn 2010).

Robotics hardware

The RCX brick used in this program was a large, specialized LEGO® brick from the LEGO® MINDSTORMS™ kit. Its functionality is derived from an embedded microcomputer (or "robot brain") and special ports where robotic parts can be connected to the internal micro-computer via wires with LEGO®-compatible connectors (Bers 2010). The RCX also has an IR receiving port that must face the IR tower connected to the computer in order to receive a program. Additional robotic parts (motors, sensors, and wires) as well as standard LEGO® bricks and crafts materials were also used to complete the robots (Fig. 2).

Fig. 1 Tangible and onscreen elements of CHERP

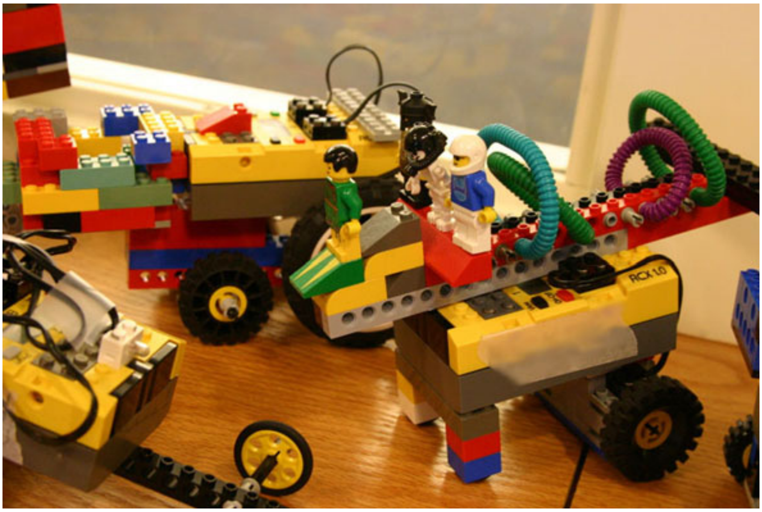

Fig. 2 Sample child-made robots

Once a robot is built, tangible programs can be uploaded to it by placing the program in the web camera's field of view, and properly placing the robot in front of the IR tower. The computer takes a photo to "see" the blocks, and then the computer 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.

The curriculum

Teachers used a six-lesson curriculum developed by the DevTech Research Group at Tufts University designed for the TangibleK Robotics Program (Bers 2010). The TangibleK curriculum introduces *powerful ideas* from computer science in a robotics context in a developmentally appropriate way. The term *powerful idea* refers to a central concept within a domain that is at once epistemologically and personally useful, interconnected with other disciplines, and has roots in intuitive knowledge that a child has internalized over a long period of time (Papert 1993; Bers et al. 2002). The powerful ideas from computer science addressed in this curriculum include: the engineering design process, robotics, control flow by sequencing and by special instructions (loops, branches, and parameters), and sensors.

These powerful ideas are taught in the TangibleK curriculum through hands-on and problem solving-based activities. The curriculum is designed for a minimum of 20 h of classroom work divided into six structured activities/lessons:

- Lesson 1 (Sturdy Building): Introduced the engineering design process and building a working means of locomotion for a vehicle.
- Lesson 2 (What Is a Robot?): Introduced to the basic ideas of robotics and programming along with the materials included in the robotics kits
- Lesson 3 (Hokey-Pokey): Addressed control flow by sequencing by programming instructions in a particular order that matched the actions of the Hokey-Pokey.

- Lesson 4 (Again and Again): Introduced the use of special instructions that control when their robots perform certain behaviors and how many times (control flow instructions)
- Lesson 5 (Through the Dark Tunnel): Introduced a light sensor or touch sensor and their corresponding programming instructions.
- Lesson 6 (The Robot Decides): Introduced new control flow instructions, "If" and "If Not."

Results

For each task assessed across the six lessons, boys' and girls' mean scores were compared (See Table 1). Both boys and girls were able to successfully complete the TangibleK curriculum, although as the lessons became increasingly difficult, both boys' and girls' scores generally decreased. Both boys and girls had their highest mean score on a particular concept in Lesson 1 (boys = 4.68 and girls = 4.46 on building a vehicle with a working means of motion) and their lowest mean score on a particular concept was in either Lesson 5 (girls = 2.73 on selecting the right instructions) or Lesson 6 (boys = 3.42 on knowing when and how to use If Nots).

Boys' and girls' mean scores on debugging abilities across the 6 lessons were also compared (See Table 2). Once again, both boys and girls generally had more trouble debugging in the later, more challenging, lessons. Both boys and girls had their lowest mean scores on debugging in lessons 5 and lessons 6.

Pearson product-moment correlation coefficients were computed to determine the relationship between gender and the concepts assessed in lessons 1–6. Being female was found to have a significant, negative correlation with the following three tasks: Lesson 2: Attaching robotic parts so that they work correctly ($r = -.312$, $N = 51$, $p = .026$), Lesson 6: Knowing when and how to use Ifs ($r = -.384$, $N = 35$, $p = .023$), and Lesson 6: Selecting the right instructions ($r = -.356$, $N = 35$, $p = .036$). Gender was not significantly correlated with any other tasks assessed in lessons 1–6 or any debugging concepts in lessons 1–6.

Looking specifically at the three tasks which were significantly correlated with gender, T-tests were performed to determine whether the boys' mean scores were significantly higher than the girls' mean scores. Boys' mean scores were found to be significantly higher than girls' on each of these three tasks. Lesson 2: Attaching robotic parts so that they work correctly, $t(49) = 2.30$, $p < .05$. Lesson 6: Knowing when and how to use Ifs, $t(33) = 2.39$, $p < .05$. Lesson 6: Selecting the right instructions, $t(33) = 2.19$, $p < .05$.

For the final project, all tasks and debugging concepts were assessed again and boy' and girls' mean scores were compared. No significant gender differences were found in the final project.

Discussion

Results indicate that the TangibleK Robotics Program is, for the most part, equally accessible to kindergarten boys and girls. Both boys and girls were able to successfully complete the curriculum and the final project. Boys scored significantly higher than girls in only two areas: properly attaching robotic materials, programming with Ifs. In all other

Table 1 Gender differences in mean scores for concepts in lessons 1–6

Lesson	Tasks assessed	Males' mean score	Females' mean score
Lesson 1: Building a sturdy, non-robotic vehicle	Vehicle has working means of motion	Mean = 4.68 (N = 28)	Mean = 4.46 (N = 24)
	Vehicle remains intact and moves as designed to move	Mean = 4.43 (N = 28)	Mean = 4.21 (N = 24)
Lesson 2: Building a robotic vehicle	Knows robot needs specific parts for specific actions and uses those parts	Mean = 4.57 (N = 28)	Mean = 4.38 (N = 24)
	Attaches all robot parts so they work correctly	Mean = 4.44* (N = 27)	Mean = 3.79 (N = 24)
	Knows how to program the robots with TUI or GUI	Mean = 4.59 (N = 27)	Mean = 4.33 (N = 21)
Lesson 3: Programming the Hokey-Pokey	Selects the right instructions	Mean = 3.96 (N = 24)	Mean = 4.17 (N = 23)
	Arranges instructions in correct order	Mean = 3.91 (N = 23)	Mean = 4.17 (N = 23)
Lesson 4: Programming using repeats	Knows when and how to use repeats	Mean = 3.64 (N = 28)	Mean = 3.00 (N = 25)
	Knows when and how to use number parameters	Mean = 3.64 (N = 28)	Mean = 3.44 (N = 25)
	Selects the right instructions	Mean = 3.79 (N = 28)	Mean = 3.52 (N = 25)
	Arranges the instructions in the correct order	Mean = 3.50 (N = 28)	Mean = 3.32 (N = 25)
Lesson 5: Sensors	Knows how/why to use sensors	Mean = 3.75 (N = 24)	Mean = 3.00 (N = 22)
	Knows when and how to use sensor parameters	Mean = 3.54 (N = 24)	Mean = 2.82 (N = 22)
	Selects the right instructions	Mean = 3.21 (N = 24)	Mean = 2.73 (N = 22)
	Arranges instructions in the correct order	Mean = 3.33 (N = 24)	Mean = 2.86 (N = 21)
Lesson 6: Programming using ifs	Knows how and when to use ifs	Mean = 4.11* (N = 19)	Mean = 3.06 (N = 16)
	Knows how and when to use If Nots	Mean = 3.42 (N = 12)	Mean = 2.91 (N = 11)
	Selects the right instructions.	Mean = 4.00* (N = 19)	Mean = 3.00 (N = 16)
	Arranges instructions in the correct order.	Mean = 4.00 (N = 19)	Mean = 3.19 (N = 16)

* $p < .05$

areas assessed, including debugging abilities, girls and boys performed comparably. Girls did not score significantly higher than boys in any areas.

Although boys scored significantly higher than girls when it came to properly attaching robotic materials in lesson 2, boys and girls did *not* perform significantly differently when it came to building sturdy vehicles with non-robotic materials in lesson 1. These results suggest that girls were equally capable of designing and building functioning structures, and it was only using the added element of robotic parts in which boys outperformed girls.

Table 2 Gender differences in mean debugging scores across lessons

Lesson	Debugging 1: Recognizes something isn't working (Lesson 1) or recognizes incorrect instructions or order (lessons 2–7)	Debugging 2: Keeps original goal or changes to an acceptable alternative	Debugging 3: Has a hypothesis of the cause of the problem	Debugging 4: Attempts to solve the problem
1	M = 4.29	M = 4.30	M = 4.24	M = 4.24
	F = 4.09	F = 4.14	F = 3.76	F = 4.09
2	M = 4.54	M = 4.22	M = 3.68	M = 3.92
	F = 4.14	F = 4.09	F = 3.68	F = 3.71
3	M = 3.68	M = 4.21	M = 3.56	M = 3.72
	F = 3.12	F = 4.20	F = 3.17	F = 3.39
4	M = 3.52	M = 3.71	M = 3.46	M = 3.63
	F = 3.52	F = 3.38	F = 2.75	F = 3.04
5	M = 2.43	M = 3.30	M = 2.45	M = 3.10
	F = 2.62	F = 2.86	F = 1.81	F = 2.15
6	M = 3.41	M = 4.00	M = 2.88	M = 3.35
	F = 2.92	F = 3.15	F = 2.33	F = 2.92

Table shows mean scores for males (M) and females (F) for each debugging task across all lessons. No significant gender differences were found in debugging abilities

This could be due to many factors including: induced stereotype threat when the project changed from a non-robotic building activity to a robotics activity, boys may have had more experience building with parts like motors (from playing with traditionally masculine toys like motorized cars), boys may have had more confidence in this task, or girls may have simply needed more time than boys to work with the robotics materials. Follow-up research is needed in order to determine the cause of differences in boys' and girls' performances in this area.

Boys may have scored significantly higher than girls in selecting the right instructions when programming with Ifs because they were more willing to take risks in this challenging lesson. Previous research by Yelland (1993) has found that when programming with LOGO, girls were less likely to take risks to achieve a goal than boys or boy/girl pairs. Lesson 6, the last lesson prior to the final project, was the most challenging lesson in the curriculum. Although girls performed comparably to boys in the other programming challenges, they may have been less inclined to take risks in this advanced lesson. Further research is needed in order to determine why boys scored significantly higher than girls when programming with Ifs.

Although boys scored significantly higher than girls in the two areas described above, when it came to the final project, boys and girls exhibited no significant differences. This indicates that both boys and girls were equally capable of using the concepts from lessons 1 to 6 in order to build and program a culminating robotics project after completing the curriculum.

Limitations and future research

This study looked solely at children's performance on building and programming tasks to see if any gender differences were present. It did not examine for gender differences in *approach* to solving each task. Future research should look at whether boys and girls approach robotics and programming differently. Are boys and girls equally confident? Do they spend equal amounts of time on each task? This study also did not interview children to see whether gender based stereotypes about programming, robotics, and engineering were already present and to what degree. A follow up study should look at differences in approach, attitudes, and opinions among kindergarten boys and girls.

Another limitation of this research was that it looked only at kindergarten aged children. It would be useful to compare gender differences in robotics and programming abilities in kindergarteners with older children. Because stereotypes become more extreme in later childhood (Martin et al. 1990), it is possible that older children will exhibit many more gender differences than the kindergarteners in this study. If this is the case, then re-thinking STEM curriculum for older children so that it is equally accessible to boys and girls will be necessary.

This study gathered its results from assessments completed by teachers and research assistants. Although these assessors were trained in order to collect accurate data, it is always possible that their own biases and opinions of the children could have influenced the data. Further research studies replicating and expanding upon this one using different testing methods would provide more support for the findings reported here.

Finally, a longitudinal study looking at the effects of introducing a robotics and programming curriculum in kindergarten should be done in order to determine long term benefits. Do girls who are introduced to this material in kindergarten exhibit less gender based stereotypes in later years? Are they more confident when approaching other types of STEM curriculum? Do they show a greater interest in STEM in later years? A long-term study following boys and girls from kindergarten through elementary, middle, and high school would be very valuable to our understanding of when and how gender based stereotypes specific to STEM emerge.

Conclusion

Results from this study indicate that both girls and boys can have a successful and rewarding experience being exposed to robotics and programming as early as kindergarten. Although research on adolescents and adults has shown that teenage boys have more self-confidence than girls in robotics and programming (Nourbakhsh et al. 2004) and men outnumber women in countless professional STEM fields (AAUW 2010), girls in this study reflected very few areas in which they did not perform equally to their male counterparts. The TangibleK Robotics Program allowed girls an introduction to robotics and computer programming in which they mastered advanced concepts and created a successful final project that they could feel proud of. This program was able to reach girls prior to the ingraining of extreme gender stereotypes, which may have contributed to their success in this traditionally masculine area. Still, longitudinal research is necessary in order to determine whether these girls, who had a successful introduction to STEM in early childhood, exhibit less gender inhibiting stereotypes in STEM fields later in life.

Reducing stereotype threat is a difficult but important challenge that teachers and parents face. While research has been done looking at gender differences in many science and mathematics areas (AAUW 2010), limited research has been done looking specifically at gender differences in robotics and programming achievement in early childhood. This is an area of research that needs more focus as men continue to outnumber women in fields like Computer Science and Engineering. If it is possible to attract the attention and interest of girls in early childhood, then significant efforts should be placed on doing so.

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