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Challenging Elementary Learners with Programmable Robots during Free Play and Direct Instruction

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Abstract

Computer programming skills are important to many current careers; teaching robot coding to elementary students can start a positive foundation for technological careers, develop problem-solving skills, and growth mindsets. This study, through a repeated measures design involving students in two classrooms at two widely-separated grade levels (first graders aged 6-7 years and fifth graders aged 10-11 years), determined if allowing students to challenge themselves with coding exercises in the experimental condition resulted in greater learning and more positive attitudes than a more structured set of exercises provided by the teacher in the control condition. Background instruction in coding and using robots occurred before the study began. Students experienced each condition twice for a two-week duration in the eight-week study; a robot performance, scored for technical and creative skills, was presented by students at the end of each two-week period. During the control condition, teachers used direct instruction to teach coding skills; during the experimental condition, students were asked to challenge themselves through free play and inquiry based learning. The results indicated that technical scores for robot performances showed the largest positive effects during the direct instructional portions of the study, while the creative score for robot performances indicated the largest positive effects during the free play rotations. Overall scores for robotic performances indicated a steady growth of skills week after week during the study. The attitudes of the participants remained positive throughout the study.

Key Words

Programmable robots, elementary students, creativity, arts integration.

Introduction

Students being educated today will compete globally for an ever-growing number of information age jobs. Companies seek candidates who think critically, solve problems creatively, work well in teams, and possess the ability to learn ever-changing technologies. Rapid changes in our world require flexibility and initiative, along with the ability to generate new, useful ideas and products. Ten jobs currently in great demand in the United States did not even exist in 2006 (Hallett & Hutt, 2016). Education for the 21st Century needs to prepare students for jobs that do not yet exist, using technology that has not yet been developed. If the United States is to retain or regain the lead in science and technology, schools need to provide meaningful experiences that nurture and develop necessary skills for scientific

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exploration, such as creative thinking and problem solving (Committee on Prospering in the Global Economy of the 21st Century, 2007).

As classrooms begin to foster more 21st Century skills, computer programming or coding has become one of the major components of STEM (science, technology, engineering and math) learning. One way teachers can incorporate these new skills into their instruction is through the use of programmable robots, such as those manufactured by Wonder Workshop Incorporated (2017) called Dot and Dash. Using these colorful robots with free applications for tablets and smartphones, students can learn basic coding skills by making the robots move, dance, and sing (Wonder Workshop Inc., 2017). Figure 1 shows the Dot and Dash robots used in the current study. Recent studies show that inquiry science in elementary classrooms can be challenging because of elementary teachers' lack of confidence in the ability to teach science (Gillies, 2015). Students may be able to take ownership of their own learning through experimental free play learning with programmable robots. Students will be required to collaborate with peers to work through challenges as they learn to code. When learning new information and solving challenging problems, having a growth mindset facilitates persistence through failures and stretches abilities through determination and curiosity. Students with a growth mindset believe they can become smarter and more skilled through challenging themselves and taking risks (Dweck, 2006). Providing elementary students with the opportunities to explore and learn computer coding in the classroom is a natural extension of literacy education. When encouraged to problem solve with robotic coding, students displayed increased perseverance and attentiveness to the importance of consistency with systems of measurement and the deconstruction of problems into component parts in efforts to solve challenges (Mak, 2014).

The current study, through a repeated measures design, determined if allowing students to challenge themselves with coding exercises in the experimental condition results in greater learning and more positive attitudes than a more structured set of exercises provided by the teacher in the control condition. To determine the effects on elementary students of different ages, a class of first graders (aged 6-7 years) and a class of fifth graders (aged 10-11 years) participated in the study.

Figure 1. Dot and Dash robots used in the current study.

Literature Review

This literature review addresses important background information related to the study. First the nature and importance of 21st Century skills are discussed. Then, concepts related to growth mindsets are explored. Finally, issues related to robotic coding are reviewed.

21st Century Skills

As recently as fifty years ago, it was sufficient for people to be able to read, write, and do simple arithmetic to hold most jobs and function in society; however, that is no longer the case for current students. Today's children must graduate from an educational system that prepares them to understand the world of the twenty-first century, where they will be expected to work with technologies that were not even invented when they were students, to make informed decisions about major engineering projects as citizens and voters, and to solve problems in their everyday lives that could not have been anticipated by their teachers (Vasquez, 2013, p. 56). Teachers need to prepare students for 21st Century employment and service to society by adding computer literacy skills to the everyday curriculum.

New Employment Opportunities and Challenges. In 2006, Facebook was in its infancy, Twitter was being launched, and no one had iPhones. Advance ten years and the world has become a very different place. Jobs exist now that we had never heard of a decade ago. In a review of technology advances in the last ten years we are reminded that the iPhone arrived in 2007 and the Android shortly after. Now nearly half the world's adults have smartphones. The demand for app designers and developers continues to increase as society's reliance on the smartphone grows. Online blogs originally began as online diaries in the late 1990's. They have evolved into a much wider readership. The Huffington Post, for example, is the world's most popular blog with more than 110 million unique monthly users (Hallet & Hutt, 2016). Additional examples of jobs that did not exist ten years ago include: Cloud computing specialist, Uber driver, drone operator, YouTube content creator and social media manager. The World Economic Forum's estimate suggests that 65% of children entering elementary school today will ultimately end up working in completely new job types that have yet to be developed. "This pace of change is only going to accelerate because of rapid advances in the fields of robotics, driverless transport, artificial intelligence, biotechnology, advanced materials and genomics, according to the World Economic Forum's latest annual Human Capital Index" (Hallet & Hutt, 2016, p. 1). To meet the needs of an increasingly technologically advanced society, the workplace has evolved from an individualized and industrialized focus to a global work environment that emphasizes knowledge, innovation, and invention of new products and services (Florida, 2003).

The Role of Schools and STEM Education. Schools are currently struggling to prepare young people for future employment. Businesses have complained that they are tasked with training new employees who lack crucial basic employment skills such as problem solving, team-work and time management (Hampson et al., 2012). Teachers need to find effective ways to teach students these basic skills needed to survive in today's fast-paced workplace. "In a rapidly changing world, education is too important to be left behind" (Hampson et al., 2012, p. 5). Twenty-first century skills are an increasingly important aspect of a complete and quality education. Many of these 21st century skills that employers are seeking can be fostered through STEM (Science, Technology, Engineering, and Mathematics) education. STEM inquiry education in a K-12 setting is important to a student-centered classroom, expansion of higher level thinking skills and problem solving, and improvement in retention, which are among benefits of STEM education as noted by Stohlman, Moore, and Roehrig (2012).

Constructionism. With hands-on learning, or constructionism, the learner is engaged in personally meaningful activities in which learning is real and shareable (Martinez, 2013, p. 32). The power of this hands-on learning comes from the fact that the learners themselves are the ones who develop the questions or challenges. Students are empowered to connect previous knowledge, inquire, explore and stretch themselves to learn new things and take risks with their learning. In encouraging making, tinkering, and engineering, the Maker Movement seeks to move learners from being dependent on teachers' delivery of information to students who individually seek out personally relevant knowledge through inquiry and a playful approach to solving problems or challenges (Martinez, 2013).

21st Century Skill Connection to the Current Study. In this study, students collaborated to create a robotic performance highlighting skills acquired after each condition rotation involving direct instruction or creative free play exploration learning. Students were encouraged to use creativity, provide peer feedback, and ultimately exhibit their collaborative work product for an authentic audience comprised of classmates and teachers. Hampson and colleagues (2012) suggest that the most effective projects share three characteristics: numerous opportunities for revisions, opportunities to critique each other's work, and a public exhibition of the final product. Redrafting, critique, and exhibition are critical pieces of the project based learning process, because they instill an ethos of high-quality work in both students and teachers (2012). Collaborative projects like the programming of a robotic performance gives students experience working in teams, problem-solving, adaptability, managing time constraints as well as the opportunity to present their work to others, all skills that will be valued by future employers.

Growth Mindset

In addition to 21st Century work skills, many argue that performance characteristics such as grit, self-control, zest, social intelligence, gratitude, optimism, and curiosity are more important and accurate measures of success than intelligence scores or even cognitive skills. Educators should focus on providing students with opportunities to build and strengthen these performance characteristics to realize their full potential in school as well as in life. These skills are critical non-cognitive skills that matter the most in the grown-up world and help to encourage individuals to develop a growth mindset (Tough, 2012).

Dweck's Mindset Work. Carol Dweck, author of *Mindset: The new psychology of success* (2006), divides learners into two distinct categories: those who believe that their intelligence and talents are natural fixed traits and those who believe that their intelligence and talents are malleable and can be increased through effort. Those who believe their aptitudes are predetermined and static are said to have a fixed mindset and those who believe their aptitudes are malleable are described as having a growth mindset. Simply stated, growth mindset is the belief that things like intelligence and ability can be changed through effort and practice.

According to Dweck (2006), all students can learn to have a growth mindset with specific feedback, challenge, opportunities to learn through failure and practice. Having a growth mindset can also help students to better deal with negative stereotypes because they learn to realize that there is no such thing as permanent inferiority (Dweck, 2006). Research indicates a strong correlation between mindset education and improved grades and engagement. One study found that students who learned the growth mindset showed increases in academic achievement, and it also noted a specific increase for African American students, who reported attitudes of valuing and enjoying school more (Good, Aronson & Inzlicht, 2003).

Managing Challenges through a Growth Mindset. A growth mindset benefits students as they are learning new information, dealing with challenging problems, discourse, and learning through multiple opportunities to fail and stretch abilities to new levels through determination and curiosity. A classroom that promotes a growth mindset encourages learning through failure and risk taking. "Success is about learning, not about proving you're smart," (Dweck, 2006, p. 16). Some parents and teachers alike think they can hand children permanent confidence by constantly praising their intelligence and talent. This constant praising of children can in fact backfire and have the opposite effect when it comes to confidence building. Focusing constant praise on intelligence and talent can result in children doubting themselves as soon as a task is difficult or anything goes wrong. "The best thing we can do for students is to teach them to love challenges, be intrigued by mistake, enjoy effort, and keep on learning," (Dweck, 2006, p. 176). Students with a growth mindset are not dependent on praise of others, as they adapt to a growth mindset, students develop the ability to build and repair self-confidence on their own. Students learning through growth mindset strategies are receiving the message that the brain is capable of growth, but must be pushed and exercised to experience the desired growth, therefore it is the student that is in control of developing or strengthening personal intelligence and talents (Brock & Hundley, 2016).

Albert Einstein is an example of an individual whose name has become synonymous with super intelligence or genius. As a young child, he was delayed in his development of speech, a late reader, and had to take his college exams twice after failing them the first time. As a grade school student, he was not considered an intelligent child or a successful student. What is interesting to note is that Einstein attributed his intelligence to an unceasing determination. He is quoted as making statements that attest to his motivation to learn, his persistence, his ability to view failure as a data leading to new possibilities to try, and his determination to succeed:

> I have no special talent. I am only passionately curious… …It's not that I'm so smart, it's just that I stay with problems longer… …Failure is success in progress… … Anyone who has never made a mistake has never tried anything new (Brock & Hundley, 2016, p. 146).

There have been criticisms of growth mindset theory, especially when it has been applied indiscriminately to all school tasks, including those tasks that should be eliminated or improved (Kohn, 2015). The curriculum must be meaningful, the pedagogy must be thoughtful, and assessments need to be authentic. Teachers need to encourage students to expend effort on worthwhile tasks without constantly conditioning students to respond to positive teacher judgments and praise. Providing feedback on how the student is progressing without an attached judgment is preferable, as too much emphasis on performance may undermine students' intellectual involvement with the work.

Growth Mindset in Computer Coding. Research shows that in the case of computer programing and coding, many learners begin the process with the notion that inherent aptitude is required to become a programmer (Scott, 2015). These beliefs inhibit the practice of teaching coding and the willingness to believe that coding abilities can be incrementally increased through challenge, risk and overcoming failures. Scott suggests that educators take an approach that focuses on improvement through illustrating weaknesses to overcome, rather than simply labeling learners with summative grades. Summative grades can be equated to a judgment of aptitude whereas specific feedback regarding weaknesses to overcome is interpreted as a path towards growth (Scott, 2015). While there are numerous studies showing the correlation between growth mindset and academic improvement (Claro, 2016, Hampson, 2012, & Rau, 2016), very few have focused on the connection between coding and mindset.

Mindset Connection to the Current Study. In the current study, strategies of growth mindset were applied by providing opportunities to grow through challenge, failure, and risk by encouraging students to explore and try new things with robotic coding. The robotic coding curriculum was current and meaningful to students, the inquiry approach was appropriate and generally motivating, and the robot performance assessments were creative, enjoyable, and authentic. An attitudinal survey was administered on a biweekly basis to ascertain changes in attitude, motivation and perceived growth.

Robotic Coding

Robotic coding is a relatively new skill that provides students with an opportunity to take risks through trial and error using growth mindset strategies. Like any language, coding is best learned while young. Today's students are already well versed with the use of technology, and, by incorporating technology into learning experiences, teachers are able to integrate school into students' lives and better engage learners both inside and outside of school (Hampson, et al., 2012).

To engage the multi grade level students in this robotics study, the Wonder Workshops Dash and Dot programmable robots were used. In 2015 Dash won Good Housekeeping's Toy of the Year award, and was Melinda and Bill Gates' favorite STEM gift for kids. Currently, over 8,500 elementary schools worldwide have purchased Dash and Dot to make computer science education fun and effective within the elementary school setting (Wonder Workshops, 2017). Although the price of these robots can be expensive for a classroom teacher to purchase on his or her own, many teachers have utilized education grants or teacher crowd sourced websites such as DonorsChoose.org to help fund these robots for their classrooms. Both teachers in this study have had success with funding robots through DonorsChoose.org and one teacher in this study was awarded an educational grant for additional classroom robots (Connecting the Public, 2017).

Motivating Problem-Solving Work with Robots. Research shows that students' confidence with math and science concepts has been increased through successful experiences with programmable robots (Thompson, 2016). Students find themselves working for hours to perfect a robot's movement sequence and the trial-and-error nurtures a growth mindset with students willing to learn through failure and risk taking. Students who considered math as a difficult subject found themselves using math, measurement, logic and sequencing to solve challenges but did not consider programing as a mathematical activity (Thompson, 2016).

One way that teachers can improve students' ability to problem-solve is through robotic challenges that allow them to learn coding. "In the new digital economy, coding is the new reading and writing—the new literacy—and it is becoming a critical mindset and set of thinking skills for success," says Idit Harel, founding CEO of Globaloria, a company that aims to teach all U.S. students how to code through video game design (McIntyre, 2016, p. 1). Coding robots engages students in real world problem solving and in mathematical reasoning, which fosters critical thinking and collaboration. In

Mak's (2014) research study, students who did not experience immediate success while coding engaged in valuable discussions, asked more questions and began to investigate and retrace their steps to collaboratively work through error analysis inquiries. When encouraged to problem solve with robotic coding, students displayed increased perseverance and attentiveness to the importance of consistency with systems of measurement and the deconstruction of problems into component parts in efforts to solve challenges (Mak, 2014). Mak's research focused primarily on coding applications and less on hands on robotic programming. In Mak's research study, students were given specific teacher initiated challenges to solve, creating a need to solve specific problems with predetermined guidelines.

Rusk, Resnick, Berg, and Pezalla-Granlund (2008) suggested four pedagogical strategies for teaching about robotics that included: (1) focusing on themes in addition to challenges, (2) incorporating art with engineering, (3) encouraging storytelling, and (4) holding exhibitions instead of competitions. Several of these pedagogical techniques were implemented in the current study, such as incorporating art and creativity into the robotics tasks, supporting storytelling, and the culminating projects of robot performance exhibitions rather than competitions.

In the current study, students alternated between direct instruction and self-initiated exploration with each of the four rotations culminating in a student-designed performance to share with the class a creative performance to highlight newly acquired skills. This self-initiated exploration is similar to project-based learning. Project-based learning offers opportunities for personalization and allows students to draw on their personal interests, passions and skills in order to create work that is meaningful to them. Effective project-based learning has few "non-negotiables" and a host of elements that students can personalize themselves. In project-based learning, students, not teachers, are responsible for personalizing the work (Hampson, el. al, 2012).

Methods

This study, through a repeated measures design, investigated if allowing students to challenge themselves with coding exercises in the experimental condition results in greater learning and more positive attitudes than a more structured set of exercises provided by the teacher, in the control condition. To determine the effects on elementary students of different ages, a class of first graders (aged 6-7 years) and a class of fifth graders (aged 10-11 years) participated in the study.

Research Questions

The primary purpose of this study was to determine if allowing students to challenge themselves with coding exercises worked better than a more structured set of exercises. This research is important because both classrooms involved in the study have Wonder Workshop Dot and Dash robots and wanted to take a closer look at the effects of prescribed tasks compared to student self-direction in coding (Wonder Workshops, 2017). The teachers were particularly interested in student engagement and actual knowledge learned with these two different conditions. Therefore, the research questions were:

1. Do students evidence more learning of coding and robot operation during a control condition of following step-by-step instruction with prescribed challenges or an experimental condition of playing around with the robot and developing one's own challenges? Skill scores on a rubric evaluating the biweekly final robot performance were used to answer this.
2. Do students evidence more creativity during the biweekly robot performance when they have worked during the immediately-prior two weeks in the control condition or in the experimental condition? Creativity scores on rubric evaluating the robot performance were used to determine this.
3. Do students report more enjoyment, perceived creativity, perceived skill improvement, or perceived cooperation during the control condition or the experimental condition? An attitude survey administered every two weeks was used to measure this.
4. Do students evidence more engagement and cooperation during the control condition or the experimental condition? Teacher observations

recorded on a behavior checklist for each group of students during one or more times each 2-week period were used to answer this question.

Research Design

This study tracked twenty-four first graders and twenty-two fifth graders through four 2-week units alternating every unit between controlled or experimental conditions (Table 1). During the controlled condition, students were given direct, step-by-step instructions from the teacher to achieve the desired outcome with the robot. During the experimental condition, students were given no direction from the teacher other than the objective. They used free play programming to achieve the desired outcome with the robot. Multiple sources of data were utilized to provide triangulation of qualitative data; student attitude survey responses, teacher observations of engagement and cooperation, and rubric scores of robot performances.

Table 1. *Study Design*

Week	First Grade	Fifth Grade
Week 0 *Before Starting Study*	Give basic instruction about how the robots work and do the most basic exercises through direct instruction	Give basic instruction about how the robots work and do the most basic exercises through direct instruction.
Study Begins		
Weeks 1 and 2	Control Condition- Direct Instruction Step by Step. Each group is evaluated for engagement and behavior with checklist at least once during this time period.	Experimental Condition: Receive minimal direction, create own challenges, play around. Each group is evaluated for engagement and behavior with checklist at least once during this time period.
Last Day of Week 2: Assessment	Present an artistic, exciting robot performance to showcase what you know; give the performance an interesting title.	Present an artistic, exciting robot performance to showcase what you know; give the performance an interesting title.
Switching Conditions		
Weeks 3 and 4	Experimental Condition: Receive minimal direction, create own challenges, play around. Each group is evaluated for engagement and behavior with checklist at least once during this time period.	Control Condition- Direct Instruction Step by Step. Each group is evaluated for engagement and behavior with checklist at least once during this time period.
Last Day of Week 4: Assessment	Present an artistic, exciting robot performance to showcase what you know; give the performance an interesting title.	Present an artistic, exciting robot performance to showcase what you know; give the performance an interesting title.
Keep Same Condition (Necessary for fair comparison of results)		
Weeks 5 and 6	Experimental Condition: Receive minimal direction, create own challenges, play around. Each group is evaluated for engagement and behavior with checklist at least once during this time period.	Control Condition- Direct Instruction Step by Step. Each group is evaluated for engagement and behavior with checklist at least once during this time period.
Last Day of Week 6: Assessment	Present an artistic, exciting robot performance to showcase what you know; give the performance an interesting title.	Present an artistic, exciting robot performance to showcase what you know; give the performance an interesting title.
Switching Conditions		
Weeks 7 and 8	Control Condition- Direct Instruction Step by Step. Each group is evaluated for engagement and behavior with checklist at least once during this time period.	Experimental Condition: Receive minimal direction, create own challenges, play around. Each group is evaluated for engagement and behavior with checklist at least once during this time period.
Last Day of Week 8: Assessment	Present an artistic, exciting robot performance to showcase what you know; give the performance an interesting title.	Present an artistic, exciting robot performance to showcase what you know; give the performance an interesting title.

Setting and Participants

This study included a total of 46 students from two classrooms located in Midwestern United States. One classroom of first-graders consisted of 24 students (12 female, 12 male) in a high poverty school (85% free and reduced-cost lunch). Four students in the first-grade class qualified for special education services. The fifth-grade classroom consisted of 22 students (11 female, 11 male) at a school with a population of students of which 29% received free and reduced-cost lunch. Three students in the fifth-grade classroom qualified for special education services.

Instrumentation

Several different instruments were used to measure student attitudes, behaviors, technical skills, and creative skills. These are discussed in the following sections.

Attitude Survey. The study measured students' attitudes of the two conditions at the end of each two-week unit including overall enjoyment and how much they perceived they had learned (Table 2).

Table 2. *Attitude Survey*

1. Circle a number below to show how much you enjoyed working with the robots during the past two weeks.											
Did not enjoy at all	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Enjoyed very much!**
Tell why:											
2. Circle a number below to show how creative you were in designing your recent robot's performance.											
Not creative at all	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Extremely creative!**
Tell why:											
3. Circle a number below to show how much you improved your skills in programming the robot in the last two weeks.											
Did not improve skills at all	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Improved skills very much!**
Tell why:											
4. Circle a number below to show how cooperative you were during the last two weeks in working with others to code the robot.											
Not cooperative at all	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Extremely Cooperative!**
Tell why:											

Behavior Observations. Students in both classrooms were observed at least once each week during the study using the Teacher Observation Checklist (Table 3). Values recorded reflect the number of times the teacher observed that student showing the specific behaviors on the day he or she was observed in their group. When teachers were not directly engaged in the teaching of a lesson during the direct instruction phases they took on the role of active participant observers and/or passive observers focusing on data collection, monitoring the social interactions and impact of each study condition on their group of students (Mills, 2011).

Table 3. *Teacher Observation Checklist*

	Student Name	Student Name	Student Name	Student Name	Student Name
Positive Behaviors					
Actively Involved in schoolwork					
Reasoned argument about ideas					
Making suggestions					
Listening well to others					
Accountable Talk for Discourse					
Praise and/or encouragement of group members					
Perseverance through challenges					
Celebration of success					
Negative Behaviors					
Complaining					
Working on other schoolwork					
Giving up					
Arguing or fighting					
Insulting others					
Discounting others' ideas					
Improper/Inappropriate handling of robots					

Robot Performance Rubric. At the end of each two-week condition, each group demonstrated their knowledge of coding the robots through a performance. Each group was scored using the Rubric for Scoring Robot Performances (Table 4 and Table 5) on a scale of 0-4 points per criterion.

Table 4. *Rubric for Scoring Robot Performances Part 1: Technical Skill Scores*

Criteria	**N/A**	**Yes, Entirely (4 pts)**	**Mostly (3 pts)**	**Somewhat (2 pts)**	**A little (1 pts)**	**No (0 pts)**
Coding Skill Criteria						
1. Did the robot performance show skill in varied movement?						
2. Did the robot performance show skill in use of sensory event coding?						
3. Did the robot performance show skill in creating a visual image?						
4. Did the robot performance show variety and combination of coding skills acquired in previous weeks?						
5. Did the robot performance utilize programming loops?						
6. Did the robot performance utilize attachments and/or accessories?						
7. Did the robot performance customize coding blocks to meet specific performance needs?						

Teacher Observations

"Teachers who undertake action research have countless opportunities to observe in their own classrooms" (Mills, 2011). Observations were a primary source of data collecting in this research study. Both classroom teachers were active participant observers and passive observers throughout the study. Active participant observers are actively engaged in teaching and monitor the effects of the instruction and make the necessary changes. These observations mostly took place during the controlled condition periods. Teachers gave step-by-step directions for students to follow, and adjusted their teaching according to how students were responding. During the experimental condition periods, the classroom teachers were passive observers focusing on what the students were doing and how they were learning, rather than giving instruction. The students were aware that the teacher was simply there to watch them, not necessarily teach them.

During observation of classroom behavior, teachers looked for contradictions or paradoxes within the classrooms as well as unintended consequences of each particular condition change (Mills, 2011). Using Mills' components of effective observation, field notes of verbatim conversations, video recordings, and anecdotal records were included in the data collection process (2011).

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Table 4. ***Rubric for Scoring Robot Performances Part 2: Creative Skill Scores***

Criteria	**N/A**	**Yes, Entirely (4 pts)**	**Mostly (3 pts)**	**Somewhat (2 pts)**	**A little (1 pts)**	**No (0 pts)**
Creativity Skill Criteria						
1. Uniqueness. Was this robot performance significantly different (in a positive way) from other student robot performances *at this time*?						
2. Humor. Was there an *intended* funny aspect to the performance?						
3. Emotional Expressiveness. Did the performance express emotion?						
4. Word Play. Was there word play in the title or in the performance?						
5. Elaboration. Was something done in an elaborate way (such as two skills combined or added materials)?						
6. Fluency. Did the robot do many tricks (compared to other groups *at this time*)?						
7. Flexibility. Did the students' performance show skills from different areas?						
8. Abstract Ideas. Did the performance title present an abstract idea or was there symbolism involved?						
9. Fantasy. Was there evidence of story characters, famous people, a holiday event, pretending, involved in the performance?						
10. Sound or Unusual Movement. Did the robot performance include sound or unusual movement?						

Data Analysis

The data process began by creating a spreadsheet for data from each classroom in the three different rubrics: Student Attitude Survey (Table 2), Teacher Observation Checklist (Table 3) and Rubric for Robot Performance (Table 4). The classroom teachers entered scores on a weekly and bi-weekly basis. In addition to entering numerical values, classroom teachers also recorded comments made by students on the Teacher Observation Checklist. Classroom teachers also entered student reasons written on Student Attitude Surveys as well as anecdotal notes taken during observations.

Research data were analyzed for recurring themes or common threads. Strategies for data analysis from Mills, "*Action Research: A Guide for Teacher Researcher,*" were utilized to ask key questions, develop a concept map, analyze antecedents, and consequences as well as display findings along with identifying missing information or issues that warrant research (2011).

Results

This study measured three areas; student-created robot performances at the conclusion of each condition rotation, student attitudes as self-reported on surveys, and observed student behaviors as reported by the classroom teachers. Results are presented for both fifth and first grade classrooms. In addition, each classroom teacher reflects on the 8-week study giving implications for classroom practice as well as suggestions for future research.

Robot Performance Technical Scores

First Grade Students' Robot Performance Technical Scores. Although the mean technical score for first graders' work, presented in Table 5, shows no overall significant difference between the control and experimental conditions, there were specific areas that favored the control condition. Varied movement had a large effect size favoring the control condition. Rubric scoring criteria of "creation of visual images" and "met specific performance needs" each had very large effect sizes favoring the control condition. The teacher suggested that the control condition was favored over the experimental condition for meeting specific performance needs because the teacher directed the students with each task, whereas in the experimental condition, students had very few guidelines. Surprisingly, there was a very large effect size favoring the experimental condition for programming loops. This gain in skills resulted from one student discovering how to program loops during weeks 5 and 6 of the study, and he taught his group members how to do it.

Table 5. *First Graders' Robot Performance Scores: Technical Scores*

	Score for Week #				Final Comparisons				
	2	4	6	8	Mean of 2 and 8	Mean of 4 and 6	Paired *t*-test *p*-value	Sig. Diff?	Cohen's *d* & Effect size
Condition	Contr	Exper	Exper	Contr	Contr	Exper			
1. Varied movement	2.00 (0.0)	2.20 (0.8)	2.30 (1.5)	2.00 (0.0)	2.00 (0.0)	2.25 (1.1)	0.15	No	-
2. Sensory event coding	2.25 (0.4)	0.95 (1.3)	0.50 (0.9)	0.00 (0.0)	1.13 (02)	0.73 (0.6)	<0.001	Yes	0.89; large favoring control condition
3.Creation of visual image	2.00 (0.0)	0.50 (0.5)	2.75 (0.4)	1.95 (0.7)	1.98 (0.3)	1.63 (0.2)	<0.001	Yes	1.37; very large favoring control condition
4. Variety and combination of coding skills	2.50 (0.5)	2.25 (1.3)	2.05 (1.3)	2.50 (0.5)	2.50 (0.0)	2.15 (1.3)	0.12	No	-
5. Program-ming loops	0.00 (0.0)	0.60 (0.9)	2.20 (2.0)	0.00 (0.0)	0.00 (0.0)	1.40 (1.4)	<0.001	Yes	1.41; very large favoring experimental condition
6. Attach-ments or accessories	0.00 (0.0)	0.00 (0.0)	3.40 (1.2)	3.75 (0.4)	1.88 (0.2)	1.70 (0.6)	0.14	No	-
7. Met specific performance needs	3.00 (0.0)	1.45 (0.5)	2.40 (1.8)	3.45 (0.5)	3.23 (0.3)	1.93 (1.0)	<0.001	Yes	1.76; very large favoring the control condition
Mean technical score	1.68 (0.1)	1.14 (0.5)	2.23 (1.1)	1.95 (0.3)	1.81 (0.1	1.68 (0.7)	0.19	No	-

Fifth Grade Students' Robot Performance Technical Scores. The mean technical skill score on Table 6 shows a small effect favoring the control condition of the study. The data show large effects favoring the control condition in the areas of varied movement, and use of programing loops, and medium effects in the scores for students modifying code to meet specific performance needs. Programing loops, sensory event coding and modification of coding blocks were taught during direct instruction blocks during the control condition of the study. The two technical scores that showed small to medium effects favoring the experimental condition were "sensory event coding" and the "creation of visual images," both of which were used for artistic drawing and dance performances during the experimental condition. Drawing and sensory event coding helped support more abstract and artistic performances students created during the experimental conditions.

Table 6. *Fifth Graders' Robot Performance Scores: Technical Scores*

	Score for Week #						Final Comparisons		
	2	4	6	8	Mean of 4 and 6	Mean of 2 and 8	Paired *t*-test *p*-value	Sig. Diff?	Cohen's *d* & Effect size
Condition	Exper	Contr	Contr	Exper	Contr	Exper			
1. Varied movement	1.91 (0.3)	2.55 (0.5)	2.27 (1.0)	1.86 (1.6)	2.41 (0.5)	1.86 (0.8)	0.001	Yes	0.82; large effect favoring control condition
2. Sensory event coding	1.55 (1.2)	0.45 (1.0)	1.18 (1.5)	0.67 (1.3)	0.82 (1.1)	1.14 (1.0)	0.05	Yes	0.30; small effect favoring experimental condition
3.Creation of visual image	1.00 (0.9)	1.00 (0.6)	2.18 (1.4)	2.90 (0.8)	1.59 (0.7)	1.91 (0.5)	0.002	Yes	0.53; medium effect favoring experimental condition
4. Variety and combination of coding skills	2.00 (0.4)	2.09 (0.8)	2.36 (0.7)	2.10 (1.4)	2.23 (0.6)	2.05 (0.6)	0.08	No	-
5. Program-ming loops	0.36 (0.5)	2.00 (0.9)	0.82 (1.1)	0.81 (1.3)	1.41 (0.9)	0.59 (0.7)	< 0.001	Yes	1.02; large effect favoring control condition
6. Attach-ments or accessories	0.36 (0.9)	1.45 (1.0)	2.09 (1.8)	2.95 (0.7)	1.77 (0.9)	1.68 (0.6)	0.30	No	-
7. Met specific performance needs	1.73 (0.8)	2.27 (0.9)	2.55 (1.1)	2.29 (1.5)	2.41 (0.7)	2.05 (0.7)	0.02	Yes	0.51; medium effect favoring control condition
Mean technical score	1.27 (0.5)	1.72 (0.4)	1.91 (0.9)	1.95 (0.9)	1.81 (0.5)	1.61 (0.5)	0.005	Yes	0.40; small effect favoring control condition

Robot Performance Creative Trait Scores

First Grade Students' Robot Performance Creative Trait Scores. Overall, the mean creative score favored the experimental condition with a large effect size. See Table 7. The creative traits that showed significant differences all favored the experimental condition except for one trait, fantasy, which will be discussed later. Specifically, there was a very large effect size favoring the experimental condition in the areas of word play, elaboration, and abstract ideas. Student project scores in fluency and flexibility also showed a large effect size in favor of the experimental condition. Not having direct teacher instruction resulted in students having more time to work on their creativity with the robots. A very large effect favoring the control condition occurred in the area of fantasy. The teacher reported students worked for four weeks (weeks 3, 4, 5, and 6) in the experimental condition, showcasing fantasy in their week 6 performances. The enjoyment of fantasy carried over into their final performances in week 8 during the control condition.

Figure 2. First grade students working on the robot performances. 2a) Using blocks to add to their robotic performances; 2b) First grader enjoying building with plastic bricks to add to robot performance; 2c) Student waiting eagerly to see the robot move; and 2d) Building a road out of plastic blocks for the robot performance.

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Table 7. *First Graders' Robot Performance Scores: Creative Trait Scores*

	Score for Week #				Final Comparisons				
	2	4	6	8	Mean of 2 and 8	Mean of 4 and 6	Paired *t*-test *p*-value	Sig. Diff.?	Cohen's *d* & Effect size
Condition	Contr	Exper	Exper	Contr	Contr.	Exper.			
1. Originality	2.00 (0.0)	1.75 (0.4)	2.80 (0.4)	2.50 (0.5)	2.25 (0.3)	2.28 (0.3)	0.39	No	-
2. Humor	1.50 (0.5)	1.75 (0.4)	3.20 (0.4)	3.00 (0.0)	2.25 (0.3)	2.48 (0.3)	0.04	Yes	0.77; medium effect favoring experimental
3. Emotional expressiveness	2.00 (0.0)	1.50 (0.5)	3.00 (0.0)	2.70 (0.5)	2.35 (0.2)	2.25 (0.3)	0.16	No	-
4. Word play	0.00 (0.0)	1.75 (0.4)	3.45 (0.5)	1.50 (0.9)	0.75 (0.4)	2.60 (0.2)	< 0.001	Yes	5.85; very large effect favoring the experimental
5. Elaboration	0.00 (0.0)	1.00 (0.7)	3.25 (0.4)	2.50 (0.9)	1.25 (0.4)	2.13 (0.2)	< 0.001	Yes	2.78; very large effect favoring the experimental
6. Fluency	0.25 (0.4)	1.55 (1.1)	2.05 (1.3)	1.75 (1.1)	1.00 (0.4)	1.80 (1.2)	< 0.001	Yes	0.89; large effect favoring experimental
7. Flexibility	1.00 (0.0)	2.00 (0.7)	2.05 (1.3)	1.50 (0.9)	1.25 (0.4)	2.03 (1.0)	< 0.001	Yes	1.02; large effect favoring experimental
8. Abstract ideas	0.00 (0.0)	1.55 (0.5)	3.00 (0.0)	1.20 (0.8)	0.60 (0.4)	2.28 (0.3)	< 0.001	Yes	4.75; very large effect favoring experimental
9. Fantasy	0.00 (0.0)	0.00 (0.0)	2.60 (0.9)	4.00 (0.0)	2.00 (0.0)	1.30 (0.5)	< 0.001	Yes	1.98; very large effect favoring control
10. Unusual movement	0.50 (0.5)	1.95 (1.2)	2.80 (1.7)	4.00 (0.0)	2.25 (0.3)	2.38 (1.4)	0.36	No	-
Mean creative score	0.73 (0.1)	1.48 (0.5)	2.82 (0.3)	2.47 (0.3)	1.60 (0.1)	2.15 (0.4)	< 0.001	Yes	1.88; very large favoring experimental
Overall mean score both	1.12 (0.1)	1.34 (0.5)	2.58 (0.6)	2.25 (0.3)	1.69 (0.1)	1.96 (0.5)	0.01	Yes	0.75; medium effect favoring experimental

Fifth Grade Students' Robot Performance Creative Trait Scores. The mean score on the creative trait scores (Table 7) shows a medium effect favoring the experimental condition, with large to very large effects in the areas of humor, abstract ideas, and fantasy, and medium effects in the areas of originality and emotional expressiveness. The teacher suggested that these effects favoring the experimental condition were due to the fact that the students were given no examples to model after and were provided very limited guidelines. The conditions of elaboration, fluency and flexibility showed small to medium effect favoring the controlled condition. The teacher suggested that these results may be due to the fact that several skills were explicitly taught during the two-week controlled condition and students designed their performances during a time when they were practicing these newly acquired skills.

Table 8. *Fifth Graders' Robot Performance Scores: Creative Trait Scores*

	Score for Week #				Final Comparisons				
	2	4	6	8	Mean of 4 and 6	Mean of 2 and 8	Paired *t*-test *p*-value	Sig. Diff.?	Cohen's *d* & Effect size
Condition	Exper.	Contr.	Contr.	Exper.	Contr.	Exper.			
1. Originality	2.55 (1.0)	2.36 (1.1)	2.91 (1.0)	3.52 (0.8)	2.64 (0.7)	3.05 (0.6)	0.01	Yes	0.63; medium effect favoring exper. cond.
2. Humor	1.82 (1.4)	0.55 (0.8)	1.73 (1.0)	2.62 (0.9)	1.14 (0.7)	2.18 (0.7)	< 0.001	Yes	1.49; very large effect favoring exper. cond.
3. Emotional expressiveness	1.64 (1.5)	0.45 (0.7)	1.36 (1.0)	1.52 (1.6)	0.91 (0.6)	1.55 (1.1)	0.01	Yes	0.72; medium effect favoring exper. cond.
4. Word play	0.55 (0.9)	0.55 (0.7)	1.45 (1.4)	2.24 (1.0)	1.00 (0.8)	1.36 (0.9)	0.10	No	-
5. Elaboration	1.55 (0.9)	2.09 (0.8)	2.82 (1.2)	2.71 (1.5)	2.45 (0.7)	2.14 (0.8)	0.04	Yes	0.41; small effect favoring control cond.
6. Fluency	1.64 (0.7)	2.00 (0.4)	2.36 (0.9)	1.95 (1.4)	2.18 (0.5)	1.77 (0.6)	0.004	Yes	0.74; medium effect favoring control cond.
7. Flexibility	1.45 (0,7)	2.00 (0.4)	2.18 (1.0)	2.00 (1.3)	2.09 (0.6)	1.73 (0.8)	0.04	Yes	0.51; medium effect favoring control cond.
8. Abstract idea	1.09 (0.9)	0.73 (1.2)	1.73 (1.5)	2.81 (1.2)	1.23 (0.7)	1.95 (0.7)	< 0.001	Yes	1.03; large effect favoring exper. cond.
9. Fantasy	1.64 (1.5)	0.91 (1.2)	2.27 (1.9)	3.29 (1.2)	1.59 (1.3)	2.45 (0.8)	< 0.001		0.80; large effect favoring exper. cond.
10. Unusual movement	2.36 (0.7)	2.45 (0.5)	2.55 (1.3)	3.19 (1.2)	2.50 (0.8)	2.77 (0.6)	0.07	No	-
Mean creative score	1.63 (0.8)	1.42 (0.4)	2.14 (0.9)	2.56 (0.8)	1.77 (0.5)	2.10(0.5)	0.003	Yes	0.66; medium effect favoring exper. cond.
Overall mean score both	1.48 (0.6)	1.52 (0.4)	2.05 (0.8)	2.31 (0.8)	1.79 (0.5)	1.90 (0.5)	0.08	No	-

Overall Mean Robot Performance Scores

First Grade. The overall mean performance scores of the technical and creative scores combined had a medium effect favoring the experimental condition. Although students showed more technical scores in their performance during the controlled condition, their overall preference was the experimental conditions where they could show more creativity and personalize their work. These findings support the ideas of Rusk et al. (2008) that effective pedagogies for teaching robotics to young students include arts, storytelling, and non-competitive final products.

Fifth Grade. The overall mean performance scores of the technical and creative scores combined, as shown in Table 8, indicate no significant difference between either the control or the experimental conditions. The overall scores do however indicate a steady growth of skills week after week during the study.

Attitude Ratings

First Graders' Attitudes. The data in Table 9 shows no significant differences between the two conditions. The attitude ratings ranged from 7.74 to 9.79, indicating that student attitudes during the whole study were positive.

Table 9. *First Graders' Attitudes*

	Score for Week #				Final Comparisons				
	2	4	6	8	Mean of 2 and 8	Mean of 4 and 6	Paired *t*-test *p*-value	Sig. Diff?	Cohen's *d* & Effect size
Condition	Contr	Exper	Exper	Contr	Contr	Exper			
1. Rating of enjoyment of robot work	9.79 (0.5)	9.00 (2.2)	9.53 (1.3)	9.05 (2.2)	9.45 (1.2)	9.31 (1.2)	0.34	No	-
2. Rating of creativity in designing robot performance	9.68 (1.0)	8.20 (2.9)	8.84 (2.3)	7.58 (2.9)	8.21 (2.3)	8.40 (2.7)	0.50	No	-
3.Rating of improved skill in programming	9.21 (1.7)	8.10 (3.0)	8.26 (2.3)	7.74 (3.3)	8.17 (2.6)	8.31 (2.3)	0.42	No	-
4. Rating of cooperation in working with others	9.05 (2.0)	8.70 (2.1)	9.00 (3.9)	8.11 (3.2)	8.29 (2.4)	8.93 (2.2)	0.31	No	-

Fifth Grader's Attitudes. Student's mean attitudes ranged from 6.86 to 9.05 with the majority of scores close to 8 (Table 10). This shows that, in general, students viewed the work positively. Students' attitude scoring showed a small effect favoring the experimental condition in the area of creativity in designing the robot performances

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Table 10. *Fifth Graders' Attitudes*

	Score for Week #				Final Comparisons				
	2	4	6	8	Mean of 2 and 6	Mean of 2 and 8	Paired *t*-test *p*-value	Sig. Diff?	Cohen's *d* & Effect size
Condition	Exper	Contr	Contr	Exper	Contr	Exper			
1. Rating of enjoyment of robot work	9.00 (1.3)	8.81 (2.2)	9.05 (1.6)	8.86 (1.6)	8.73 (1.7)	8.93 (1.2)	0.31	No	-
2. Rating of creativity in designing robot performance	8.77 (1.5)	8.24 (1.9)	8.32 (2.4)	8.82 (1.7)	8.09 (2.0)	8.80 (1.4)	0.04	Yes	0.41; small effect favoring experimental condition
3.Rating of improved skill in programming	8.48 (2.0)	8.29 (2.1)	7.82 (2.30	6.86 (3.2)	7.86 (2.3)	7.32 (2.6)	0.16	No	-
4. Rating of cooperation in working with others	7.82 (2.4)	7.81 (2.9)	7.68 (3.0)	8.09 (2.0)	7.57 (2.8)	7.95 (1.5)	0.21	No	-

Student Behaviors

First Graders. Teacher-observed first grade student behaviors are shown in Table 11. Overall, the mean of positive behaviors did not show a significant difference between conditions. However, there was a small effect favoring the experimental condition for listening well to others. The teacher encouraged students to make sure everyone's ideas were heard during the experimental condition weeks. There was also a medium effect size for accountable talk for discourse for the control condition.

The overall mean of negative behavior showed no significant difference between the two conditions, as well as no significant difference in any of the seven areas. The first graders responded well to learning robotics and had very few behavior problems.

Fifth Graders. Overall the mean of positive behaviors, as shown in Table 12, indicates a medium effect favoring the experimental condition, with medium to large effects favoring the experimental condition in the observations of reasoned arguments, making suggestions and praise and encouragement of group members. Small effects favoring the experimental condition were noted in the observation of students listening well to others and use of accountable talk.

The overall mean of negative behavior showed no significant difference between the controlled or experimental condition (Table 12). The data indicated a small effect in the control condition in the area of arguing or fighting and a medium effect for the experimental condition in regards to improper handling of robots. Note that negative behaviors were very small numbers in general and the negative behaviors were minor arguments between group members or the spinning of the spherical robot.

Table 11. *Teacher's Observations of First Grade Student Behaviors during Robot Lessons*

Teacher Observation	Mean number of times each student exhibited this behavior per week during robot lessons		Comparison of Means		
	Control Condition	Experimental Condition	Paired *t*-test *p*-value	Sig. Diff.?	Cohen's *d* and Effect Size
Actively involved in work	0.50 (0.3)	0.59 (0.4)	0.16	No	-
Reasoned argument about ideas	0.08 (0.1)	0.05 (0.1)	0.16	No	-
Making suggestions	0.30 (0.2)	0.23 (0.2)	0.14	No	-
Listening well to others	0.20 (0.3)	0.33 (0.3)	0.03	Yes	0.43; small effect favoring the experimental condition
Accountable talk for discourse	0.06 (0.1)	0.01 (0.1)	0.01	Yes	0.50; medium effect favoring the control condition
Praise or encouragement of group members	0.07 (0.2	0.08 (0.1)	0.41	No	-
Perseverance through challenges	0.06 (0.1)	0.03 (0.1)	0.19	No	-
Celebration of success	0.01 (0.1)	0.00 (0.0)	0.16	No	-
Asking another group for advice	0.09 (0.2)	0.11 (0.2)	0.37	No	-
Mean of positive behaviors	0.15 (0.1)	0.16 (0.1)	0.36	No	-
Complaining	0.29 (0.3	0.21 (0.3)	0.13	No	-
Off task	0.21 (0.4)	0.18 (0.3)	0.37	No	-
Giving up	0.09 (0.2)	0.08 (0.2)	0.37	No	-
Arguing or fighting	0.21 (0.3)	0.13 (0.2)	0.07	No	-
Insulting others	0.04 (0.1)	0.01 (0.1)	0.13	No	-
Discounting others' ideas	0.05 (0.1)	0.08 (0.1)	0.19	No	-
Improper handling of robots	0.04 (0.1)	0.09 (0.2)	0.13	No	-
Mean of negative behaviors	0.13 (0.2)	0.11 (0.1)	0.23	No	-

Table 12. *Teacher's Observations of Fifth Grade Student Behaviors during Robot Lessons*

Teacher Observation	Mean number of times each student exhibited this behavior per week during robot lessons		Comparison of Means		
	Control Condition	Experimental Condition	Paired *t*-test *p*-value	Sig. Diff.?	Cohen's *d* and Effect Size
Actively involved in work	0.99 (0.2)	0.89 (0.2)	0.04	Yes	0.50; medium effect favoring control cond.
Reasoned argument about ideas	0.49 (0.3)	0.95 (0.5)	<0.001	Yes	1.12; large effect favoring experimental condition
Making suggestions	0.84 (0.5)	1.17 (0.7)	0.05	Yes	0.54; medium effect favoring experimental condition
Listening well to others	0.57 (0.3)	0.69 (0.2)	0.05	Yes	0.47; small effect favoring experimental condition
Accountable talk for discourse	0.47 (0.5)	0.66 (0.5)	0.02	Yes	0.38; small effect favoring experimental condition
Praise or encouragement of group members	0.23 (0.2)	0.38 (0.3)	0.05	Yes	0.59; medium effect favoring exper. condition
Perseverance through challenges	0.63 (0.2)	0.68 (0.2)	0.16	No	-
Celebration of success	0.45 (0.4)	0.50 (0.4)	0.35	No	-
Asking another group for advice	0.14 (0.1)	0.24 (0.2)	0.06	No	-
Mean of positive behaviors	0.53 (0.2)	0.68 (0.2)	<0.001	Yes	0.75; medium effect favoring exper. cond.
Complaining	0.15 (0.2)	0.20 (0.2)	0.10	No	-
Off task	0.27 (0.3)	0.28 (0.3)	0.45	No	-
Giving up	0.08 (0,2)	0.08 (0.1)	0.50	No	-
Arguing or fighting	0.19 (0.4)	0.06 (0.2)	0.03	Yes	0.41; small effect for control condition
Insulting others	0.02 (0.1)	0.01 (0.1)	0.33	No	-
Discounting others' ideas	0.06 (0.1)	0.07 (0.2)	0.40	No	-
Improper handling of robots	0.01 (0.1)	0.08 (0.1)	0.03	Yes	0.70; medium effect for experimental condition
Mean of negative behaviors	0.11 (0.1)	0.11 (0.1)	0.50	No	-

Discussion

Technical Skills

First Graders. The most interesting result in technical skills was the very large effect favoring the experimental condition in the area of using programming loops. During weeks 6 and 7, one student discovered how to use loops and showed the members of his group. From that point, several members incorporated loops into their final routine. This coding procedure was a skill that the teacher did not explicitly teach, because the first graders were still learning many more basic aspects of the robot and programming. The students took ownership of their learning by not only applying it, but also teaching their peers how to apply it, as well. This hands-on learning is consistent with Martinez' research (2013) of seeking out relevant knowledge through inquiry and a playful approach to solve problems or challenges.

The largest effect size in technical skills was in meeting specific performance needs. The study favored the control condition. During the experimental conditions, students became very wrapped up with their 'stories' that they often forgot about coding, or ran out of time to implement all of the coding they intended to include in their final performance. They had more opportunities to disguise the Dash robots with their voices, Lego attachments, and blocks which they enjoyed, but also distracted them. In the control condition, they were told directly what they had to showcase; therefore, paid more attention on the coding aspect than the storytelling.

Fifth Graders. The mean technical scores of the data show a small effect favoring the control condition, but the technical scores for each rotation increased constantly throughout the study, regardless of condition. This latter finding indicates that students learned technical skills under each condition. The data indicate large effects in the areas of varied movement, and use of programing loops, and medium effects in the scores for students modifying code to meet specific performance needs. Programing loops, sensory event coding and modification of coding blocks were taught through direct instruction blocks within the controlled condition of the study. These skills carried over into the performance design aspects of the study during the controlled condition portions of the study. Figure 3 shows fifth graders working on technical aspects of their robot performances.

During a lesson on manipulating blocks of code to fit specific needs, the students were asked to use the robot to draw triangles with specific attributes. A pair of students who routinely struggle with mathematics were overheard using academic language to make reasoned arguments and provide ideas to adjust the code to draw an equilateral triangle. Upon successful completion of an equilateral triangle the students outwardly celebrated their success and when questioned how they knew they had succeeded, they very confidently listed the specific requirements of an equilateral triangle using academic terminology. These two students used a sequence of trial-and-error and real-world problem solving using mathematical reasoning. When the class was asked to reflect on the triangle activity they rated it as one of the hardest but most satisfying math lessons of the entire year. Consistent with Thompson's (2016) research introducing coding to elementary students through the introduction of maker spaces largely devoted to robots, students did not consider programing as a mathematical activity, however through programing their confidence with math and science concepts increased as they found themselves using math, measurement, logic and sequencing to solve the triangle challenge.

Figure 3. Fifth grade students working on the more technical aspects of their robot performances. 3a) Students challenging each other to a game of robotic pong; 3b) Robot drawing flowers on the table top; 3c) Figure eight race performance; and 3d) Students setting up random challenge course to test sensory event coding skills.

Creativity

First Graders. Out of the ten areas of creativity assessed by the teacher using the rubric for scoring robot performance, the first graders showed significant differences between conditions favoring the experimental condition in seven areas. The only area in which the control condition was favored was in fantasy. The first-grade students had used a lot more fantasy storytelling during weeks 5 and 6 (experimental). Their creativity carried over into the final 2 weeks (control) still using characters like monsters and block structures to tell a story. Many of the first-grade students also discovered that the blocks they had available to them starting in week 3 fit perfectly into the Lego bricks attachment, creating arms or claws for Dash. One group of female students spent a lot of their time in the final performance creating colorful ponies using Legos, which was unique from the other groups. This showcased their personal interests which is a positive outcome in using project based learning as noted by Hampson et al. (2012). Because the students were just given the desired outcome, they could personalize elements such as accessories for their final performance. Hampson et al. says "it is the students, not the teachers, who are responsible for personalizing the work" (2012). In the first two weeks of the study, the instruction focused primarily on movement and the primary functions of the robot. It was in the experimental condition that students discovered the use of sounds, even recording their own voices to add emotion and humor to their performance. The mean creative score showed a very large favoring of the experimental condition with the first-grade students.

Fifth Graders. The mean score on the creative trait scores show medium effect favoring the experimental condition, with large to very large effect in the areas of humor, abstract idea, and fantasy, and medium effect in the areas of originality and emotional expressiveness. Students likely scored better on creative measures during the experimental condition because they allowed the opportunity to free play explore abstract ideas and storylines. Without the interruptions of scripted direct instruction, the students were able to develop and enhance create threads in their programing performances. The conditions of elaboration, fluency and flexibility showed small to medium effect favoring the controlled condition, the teacher suggested that the controlled condition favored these particular categories because the students were alternating between practicing specific skills through direct instruction and working on their performances and multiple skills were included in following performance. Some notable creative performances included prom night, a comedy show, a two-act play, basketball game, ghost stories around a campfire, flower drawings, and a runway fashion show. See Figure 4 for some of these fantasy –related performances. Students showed increasing tendencies towards a growth mindset as described by Carol Dweck (2006), as the study progressed students continued to push themselves beyond previous limitations, choosing to deal with challenging problems learning through failure and stretching abilities to new levels through determination, curiosity and the acceptance of failure as a necessary path to growth.

The overall mean performance scores of the technical and creative scores combined indicated no significant difference between either the control or the experimental conditions. The overall scores do however indicate a steady growth of skills week after week during the study.

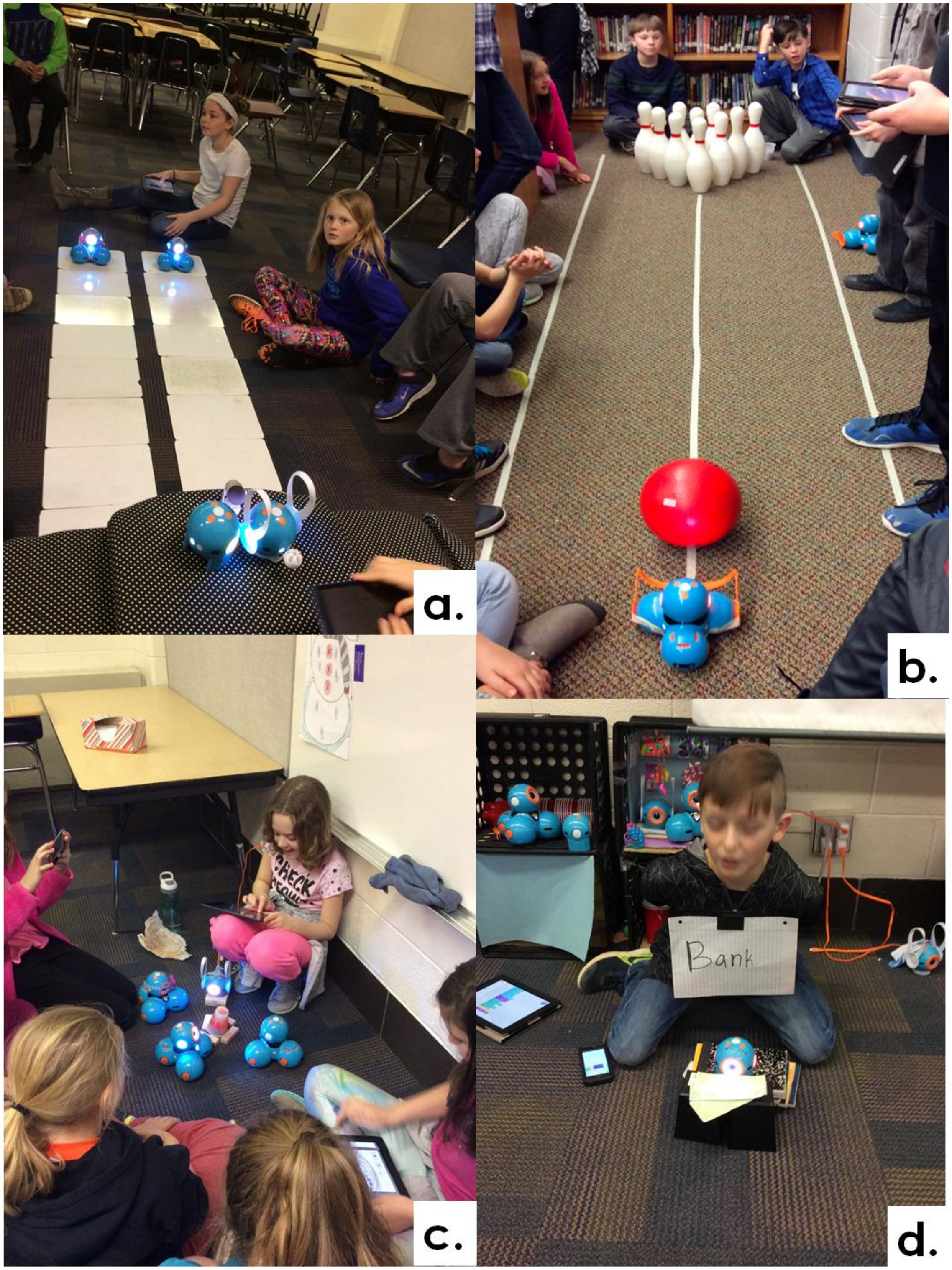

Figure 4. Fifth graders' robot performances that included elements of fantasy. 4a) Fashion show with runway; 4b) Bowling alley; 4C) Robots at a campfire; and 4d) Bank robbery, "Put your hands up" dance presentation.

First Grade. Although there was no significant difference found between students' attitudes between the control and experimental conditions of this study, the scores in Table 9 show that the first graders had a positive and joyful experience over the 8-week period. Working collaboratively in the same group for an extensive time period, using technology, and learning to code was a new experience for many of these students who have only been in school for a couple of years. In Table 9, creativity of design, improvement of skills, and cooperation in working with others did score slightly higher in the mean of the experimental condition than the mean of the control condition.

Fifth Grade. Students' attitude ratings showed a small effect favoring the experimental condition in the area of creativity in designing the robot performances. Observations during the first week of the study revealed a tendency for students to demonstrate a fixed mindset towards coding skills with many students blaming robots and the computer application for errors and students' inability to successfully manipulate the robots. One specific case in point was a talented and gifted student who became very upset with the process, calling it stupid and refereed to his robot as "jankie and broken." For several days, this student laid his head on the floor and disengaged from the process altogether. For the first three days of the study the majority of the students were frustrated, stated that they were unable to code, or blamed external factors for their lack of coding skills and displayed a fixed mindset consistent with the findings of Scott's (2015) study stating that many learners begin the process of coding with the notion that inherent aptitude it required to become a programmer.

The majority of fifth grade students have expressed a desire to continue coding through participation in a weekly programing club during recesses, and many have requested parents purchase Dash and Dot robots for home use. Since the conclusion of the study, three students' parents have purchased Wonder Workshop's Dash and Dot for their child's home use and at least three more will be receiving robots in the near future. This study has enabled students to incorporate technology-based learning experiences in school to engage them with 21st Century skills both inside and outside the classroom. This increased engagement is consistent with Hampson, et al.'s (2012) research that today's students are well versed in the use of technology and by incorporating technology into learning experiences teachers can integrate school and 21st Century skills both inside and outside of the classroom.

Behavior Observations

First Grade. There was a small effect favoring the experimental condition for listening well to others. During the experimental condition, the students had many ideas and the teacher explained that they needed to work together and listen to everyone to have the best success in their performance. This constant reminder impacted the students' conversations with each other. Figure 5 shows first grade students engaged in the study activities.

There was a medium effect favoring the control condition for accountable talk for discourse. Students had four weeks of experimental condition where they could add lots of their own ideas without being disagreed with too much. In the final two weeks of the study, they were forced to agree and disagree with each other's ideas a lot more with the teacher directed instructions. They no longer had as much creative freedom to incorporate everyone's ideas, which resulted in more accountable talk being observed by the teacher.

Overall, the first-grade students had few negative behaviors displayed in the 8-week study. Many times, they were frustrated if they were missing a group member due to being absent, or they lost a group member due to a student moving, which happened four times during the 8-week study. Because they were young, they were quick to forgive their friends and move forward with their work. The negative behaviors were usually seen by the same handful of students throughout the eight weeks. Although the first graders were frustrated at times, they did not give up and pushed through their challenges, which displayed growth mindset characteristics that model Dweck's idea of teaching students to relish challenges, to be intrigued by mistakes, to enjoy effort, and to continue learning (Dweck, 2006).

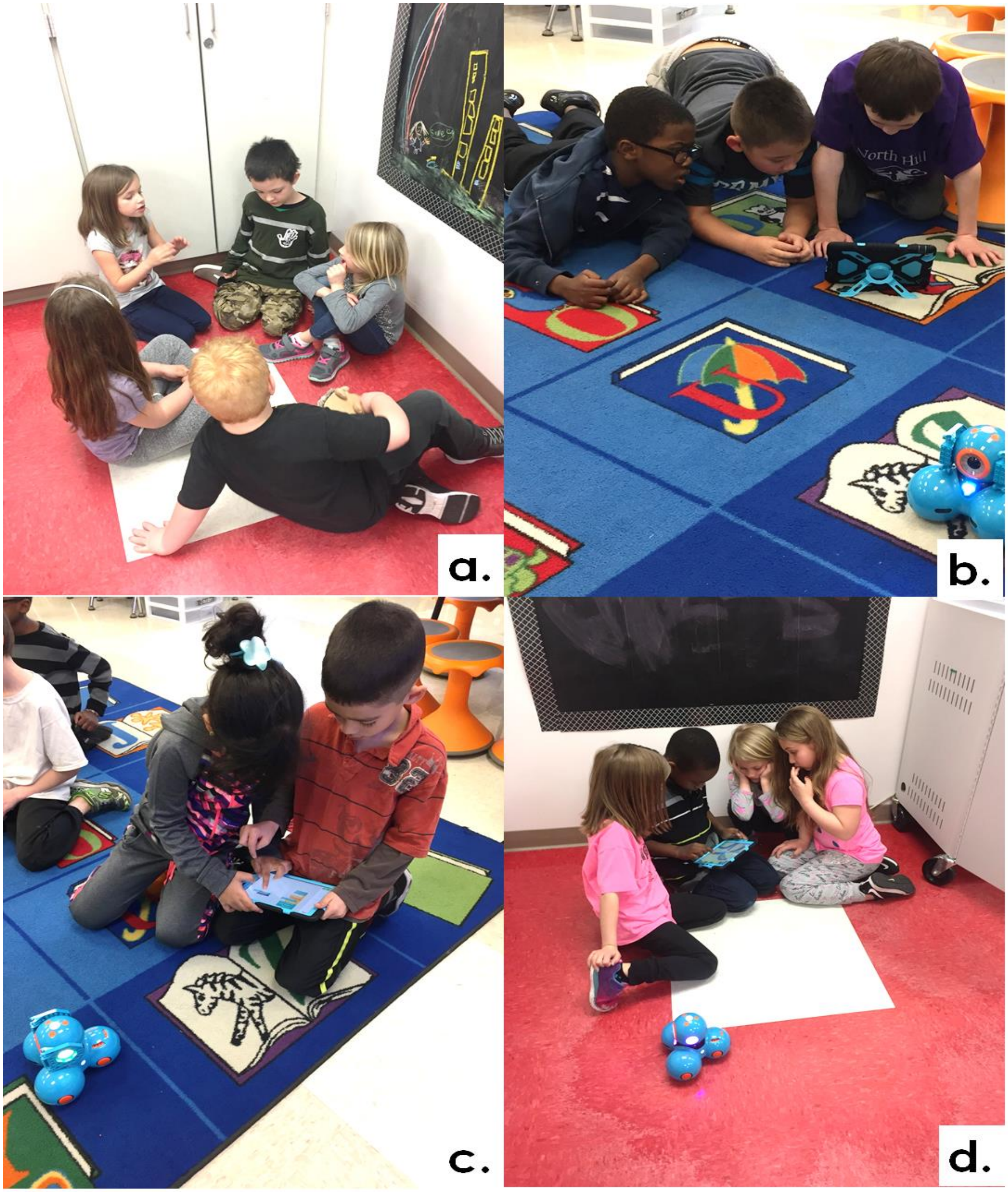

Figure 5. First grade students engaged in robot work. 5a) Listening to each other's ideas; 5b) Collaborating on robot performance; 5c) Teaching a peer a coding skill; and 5d) Problem solving to work through a robotic challenge.

Fifth Grade. Overall, the mean of positive behaviors indicates a medium effect favoring the experimental condition, with medium to large effects favoring the experimental condition in the observations of reasoned arguments, making suggestions with praise and encouragement of group members. Small effects favoring the experimental condition were noted in the observation of students listening well to others and use of accountable talk. On or around the fourth day of the study, one of the groups made a breakthrough with programing and the students' mindsets began to change rapidly as students shared success stories and ideas to overcome coding challenges with each other. In approximately one week's time, the group began to make the transition from a fixed mindset to a growth mindset regarding the programming of the robots. The hands-on learning involved in creating the unique performances for peers during the condition rotations engaged students in authentic learning, higher level thinking skills and problem solving. Consistent with Mak's research study (2014), students who did not experience immediate success engaged in valuable discussions, asked more questions and began to investigate and retrace steps collaboratively to work through error analysis, while showing increased perseverance. Students were engaged in personally meaningful activities in which learning was real and shareable. Students were notably excited on performance days, wanting to make sure all students were available during performance times. Each team was provided with specific feedback from peers regarding what aspects of the performance peers found most impressive; questions peers had about specific coding aspects; and suggestions others had to enhance future performances.

Students collaborated, designed and coded unique performances for an authentic audience and the students themselves developed the challenges and continually questioned themselves during the learning process, moving the learners from dependency on the teacher's delivery of information to students who independently sought out relevant knowledge through inquiry and peer collaboration. The results of this study demonstrated very similar learner behaviors to the Martinez, Maker Movement study (2013).

The overall mean of negative behavior had no significant difference between the controlled or experimental condition. The data indicated a small effect in the controlled condition in the area of arguing or fighting and a medium effect for the experimental condition in regards to improper handling of robots. It is important to note that negative behaviors were very small numbers in general and the negative behaviors were comprised of minor arguments between group members or the spinning of the spherical robot.

Teacher Reflections

First Grade. The first graders were originally placed in four groups of six students each due to limited coding resources including robots and iPads. Of those four groups, only one remained intact throughout the eight weeks, leaving two groups with five students and one group with only four students. Looking back, groups of six was too big for this study. Groups of four would have probably worked better, but the groups would have had less time to work on their performances.

Before beginning the study, the teacher did allow the students time to explore with the robots some and taught them the basics of the robot and coding in total about three days. This was by splitting the class into two large groups. This would have worked better in the four groups the students were going to be working in for the study and allowed the students a better opportunity to understand the robots before working with them for the next eight weeks.

Fifth Grade. While teaching programing loops through direct instruction the teacher used the example of a dance, specifically "The Chicken Dance," to demonstrate the use of loops or repeats in real life events. After the presentation of the loop lesson, all groups with the exception of one presented a performance featuring the robot performing a dance routine. This was the only instance in which the performances were similar across the board. In hindsight, instructors need to be mindful when presenting examples during direct instruction, so as not to influence or distract from individual creativity. A better approach would have been to give several examples or have students brainstorm real world examples of loops or repeats.

For purposes of organization and quick transition each pair of programmers was given a plastic crate to store and organize their robots Dash and Dot per pair as well as their iPad and accessories being used during each robotic performance cycle. One of the unexpected outcomes of this study was the level of personification the students attributed to their individual robots. Students referred to crates as robot dorms and decorated them as such with bunks, dressers, and other accessories. See Figure 6. Each pair also renamed their respective robots with unique names referring to them by their given name while programing. What began as students coding morphed into students nurturing and teaching their respective "pet / infant" new skills. Students transitioned from the beginning of the study from complaining that the robots were junk and the computer programing would not work to excitedly stopping classmates and teachers to watch what they "taught" their robot to do.

At the conclusion of the study when the students were asked to remove name tag stickers from robots and place them into a community or shared container, without identifiable markings, the students showed signs of emotional distress and were distraught over the thought of others using their robots or mishandling them. Students were concerned that they would not be able to locate "their" specific robot for future coding. When students were reminded that the robots were all exactly alike they argued that individual robots had personalities and quirks that could only be understood after working with them over a period of eight weeks. Several parents also indicated that the students were disturbed for multiple days following the conclusion of the survey that the robots were being comingled and taken away from their homes and student caretakers. This emotional connection is consistent with Turkle's study, "Authenticity in the age of digital companions," in which Turkle observed that when a digital creature or object such as the Tamagotchis, a toy fad from 1997, required children to become parents or nurture a digital creature, children became attached and began to feel connected and even empathized with the digital companion. In this study, students took on the role of caregivers and nurturers as they were training or teaching their respective robots new skills while as they created robot-to-robot and robot-to-child interactions. Turkle's research also indicated an attachment children formed to the robotic toy Furby. The Furbies had given the children the feeling of being successful caretakers, very similar to Dash and Dot creating a feeling of success as programmers for students in this study. In the Turkle study, even when Furby robots began to break, most students refused to accept a replacement. They were not about to "turn in" their sick babies.

Figure 6. Robot dormitory decorated by fifth grade students.

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Conclusion

Summary of Findings

The findings of the current study indicated, overall, there was not one particular condition favored concerning programmable coding. Both classrooms benefitted from the combination of direct instruction and free play programming. The teachers agreed that robotic coding in the elementary classroom not only teaches students coding language, but also encourages storytelling and creativity. The element of performing for an authentic audience of peers was highly engaging and a large reason that students were on-task and motivated to improve their coding skills. Students found the study to be enjoyable and overall a positive experience, as reflected in their attitude surveys.

Implications for Classroom Practice

When introducing programmable robots to students, both teachers identified a strong need for some type of introductory direct instruction to eliminate frustration and facilitate learning essentially an entirely new language. Both teachers concluded it was important to allow students ample time to work uninterrupted with robots and coding; allowing students frequent and consistent access to the robots facilitated a growth mindset when it came to coding and programming abilities.

Suggestions for Future Research

Both teachers have expressed a desire to repeat the study with modifications of condition patterns, expressed a desire to trial back-to-back control conditions followed by experimental conditions. In addition to placing the control conditions at the beginning of the study teachers would also like to research the effects a longer study period with delivery of direct instruction of one single skill at the beginning of a rotation, followed by one to two weeks to explore the new skill in a free play or experimental environment.

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