Learning Through Games: How Math Games Can Enhance Education

by

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Abstract

This thesis presents two research studies aimed at increasing our knowledge about how games can be used in math education. A number of studies have explored the effects of games in classrooms. However, their effects vary across study contexts and it is not yet clear the best ways to implement them. While prior research shows that numerical linear board games are effective learning activities in preschool classrooms, the first study presented aims to replicate and add to previous research by exploring the effects of numerical linear board games when presented in different formats. Board games are typically studied in a table top version. We introduce a physically active, life-size, walkable version, which is based on an embodied cognition perspective. The second study presented in this thesis is an overview of a professional development workshop where teachers and students played technology-based games and then designed and created their own games. We explore the effects of playing teacher-created games on student learning as well as the implications which creating games can have on their development of computational thinking skills.

Keywords: Embodied cognition, educational games, learning technologies

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Part 1: Introduction

Math skills are important to develop early in life, as they are strong predictors of later academic success (VanDerHeyden & Burns, 2009). These skills, and differences in math achievement are also predictive of differences later in life (Lee, 2013; Parsons & Bynner, 2005). Thus, it is important for children as young as preschool age to begin developing strong math skills. It is also important for teachers and researchers to develop and examine different educational learning activities for students to practice and improve on these skills.

Beyond math, another set of skills that has risen in importance recently is computational thinking (Wing, 2006; Weintrop et al., 2016); defined as investigating problems and formulating solutions that can be implemented with technology. As our world becomes increasingly reliant on technology, it is valuable for today's students to learn computational thinking skills in order to successfully use technology. Beyond just computer science, computational thinking skills are relevant in most disciplines and can be applied to a wide range of problems, from creating algorithms to assemble a DNA sequence to using simulations to derive the laws of glasses (Weintrop et al., 2016). It is important for teachers and researchers to work together to design and implement classroom activities to promote learning computational thinking skills.

One type of activity often used in classrooms, which have the potential for teaching both math and computational thinking, are games. In classrooms, students can both play games as well as design and create them. It has been noted that games have tremendous educational potential (Egenfeldt-Nielsen, 2011). Well-designed games give students opportunities to interact with a broader range of knowledge, explore ideas, understand rather than memorize, form collaborations with other students and develop theories and test their thinking (Squire & Jenkins, 2003). Games can be a natural way to get students to engage with educational content and have been used specifically to successfully teach math concepts (Kebritchi, Hirumi & Bai, 2010; Siegler & Ramani, 2008; Wang & Hung, 2010). Games can also be used across different ages and skill levels.

Since substantial research has shown that games can be valuable educational tools, the main goal of this thesis is exploring games as a vehicle to promote learning, across ages and contexts. To do so we include two studies which show how games can be used as learning activities to increase math learning as well as introduce computational thinking skills. The goal of this introduction is to provide a broad overview of existing research on the use of games for learning from early childhood to college and across disciplines.

Chapter One: The Use of Games For Learning

Play is an important part of childhood. Play allows children to explore their environment and problem-solving in creative and imaginative ways (Broadhead, 2006). Through play, children can develop and test new ideas about the world around them. Play has been shown to support intellectual development, as well as social, emotional and physical development (Broadhead, 2006). Because of its positive impacts on learning, play is an important aspect of children's lives.

Playing games in particular has been shown to have positive effects on learning both in and out of the classroom (Steinkuehler, Squire & Barab, 2012, Habgood & Ainsworth, 2011, Lester et al., 2013). Games foster engagement, excitement, motivation and teamwork as children play and learn (Devlin, 2011; Baroody, Eiland & Thompson, 2009; Griffin, 2004; Tournaki, Bae & Kerekes, 2008). Games are even more enticing as they are adaptable and allow for teachers to customize them to individual students' needs and levels (Wang & Hung, 2010). They provide a natural environment to explore the cycle of failure, effort and final success, enabling children to have an open mind for enhancing academic skills such as logical thinking and literacy (Chou, 2017). Kapp (2012) describes games as an "ideal learning environment" in that they allow players to fail and encourage out of the box thinking. Prior research suggests that games are an important tool in education. Games may provide benefits to students above and beyond typical classroom practices and can serve as effective, alternative learning activities.

Classic Games

Children begin playing games at an early age and therefore, games familiar to many students. Many are introduced to beginner games such as *Candyland, Go Fish or Chutes and Ladders* either at home, or at school before entering formal schooling. While board games are fun to play, more importantly, they can have a profound impact on student's educational achievement (Hinebaugh, 2009). Important lessons can be learned from playing board games as a child, and these lessons extend into adulthood. Research has shown that the educational skills developed through board game play leads to academic success. Children develop strategic skills through games like *Stratego* and *Checkers*, vocabulary skills through *Scattergories* and *Scrabble,* counting and math skills through *Parchessi* and *Chutes and Ladders* and numerous other skills through many other games. Playing traditional board games has been shown to accelerate learning and development in younger children, allowing them to understand abstract concepts at an earlier age and eventually leading to higher achievement in math and science (Hinebaugh, 2009).

Hinebaugh (2009) identified specific board games and explained the mathematical affordances of each one. For example, *Connect 4* promotes math skills such as pattern recognition, as well as higher math skills such as charting and graphing which are fundamental to geometry. As players take their turn placing a piece, they map out coordinates and through continued play, these fundamental graphing skills become ingrained and familiar. Playing *Connect 4* can also help develop metacognition skills as players continually test and alter different strategies and hypotheses each game.

Another classic game, *Othello*, provides ample opportunities to develop math skills. When playing, players must map out the consequences of each move, taking into account their gain as well as possible losses on their opponents next move. Players must do multiple math equations in their head when planning each move to maximize their turn.

Classic games such as *Chess* and *Checkers*, have even been incorporated into some schools systems' curriculum. By incorporating these games, students learned critical thinking and problem solving skills and also increased their math and science standardized test scores (Hinebaugh, 2009). One study found that teaching third graders how to play *Chess* over 30 hours of instruction increased their math achievement scores with an effect size of .34 (Boruch & Romano, 2011). The use of games in the classroom even extends beyond K-12 education as some colleges use *Mastermind,* a classic code breaking game, to teach mathematical proofs (Bogomolny & Greenwell, 1999; Strom & Barolo, 2011).

Other games have also been played in educational contexts. For example, one study found that the playing of popular board games, such as *Blokus*, increased 9th grade students' spatial abilities as well as their interest in spatial ability learning (Ching, Yen-Chih, Yeh & Lou, 2017). It is important to note that one reason to use games in the classroom may be to increase student engagement along with the possibilities to increase learning.

Games Designed for Education

Beyond traditional board games, researchers and teachers have designed games to target specific skills they want children to learn. Baroody, Eiland & Thompson (2009) examined the effects of an intervention consisting largely of game based activities designed by researchers (Baroody, 1987, 1989; Baroody, Baroody & Coslick, 1998; Wynroth, 1986) to increase children's number sense skills . At-risk four and five year olds played manual games which involved several concepts and skills around number sense, three times a week for five months. The preschoolers showed significant improvement on measures of number sense after completing the intervention. While this study covered a significant amount of time, it shows that consistent integration of researcher designed games into a preschool curriculum has positive benefits on children's math skills and highlights the importance of games designed around specific learning goals.

Other programs have been designed to increase children's number sense skills. For example, Number Worlds was specifically developed to teach number sense to PreK-2nd graders. Number Worlds is designed based on five cognitive development principles; *1) build upon children's current knowledge, 2) follow the natural developmental progression when selecting new knowledge to be taught, 3) teach computational fluency as well as conceptual understanding, 4) provide plenty of opportunity for hands-on exploration, problem-solving and communication and 5) expose children to the major ways number is represented and talked about in developed societies.* Several studies (Griffin, 2004) show the positive effects of Number Worlds on children's conceptual knowledge of number and number sense, especially with children from low-income backgrounds who were able to attain an equal level as their peers. Number Worlds was designed specifically around cognitive development principles which may account for some of its success. It is important to design games for learning around current theory to maximize their potential to increase learning.

Traditional games, such as *Checkers* and *Monopoly*, have also been adapted to match curricular content. One study used game playing to teach college students about the ethics of research. Rush (2014) designed a game along the lines of *Candyland* but introduced ethics topics throughout the game. While there was no formal assessment of the game's effectiveness, the author reports that playing the game allowed students to reach out and express themselves, where they previously had not. Students were engaged and enjoying themselves while reaching the learning outcomes for the class (Rush, 2014). This study displays the option of adapting existing games to meet curricular needs. Games are a good way to introduce content to students in a fun and engaging way.

Technological Games

While board games are less common in K-12 classrooms, games can take on many forms. More recently, technological games have become more prevalent in classrooms. Game-based learning environments are a common form of a technological game in which students interact in an online virtual environment. One example of this is *Crystal Island* (Rowe, Shores, Mott & Lester, 2011) where students explore microbiology through real life situations and problems they need to solve. Students have to find the source of a disease and play a character in the game to find the answers they need. This program is designed for middle school science, and studies have shown that students make significant learning gains after interacting with the program.

Habgood and Ainsworth (2011) created another technology game called *Zombie Division* for 7-8 year olds, which integrates math into a 3D combat adventure where enemies are mathematically divided to be defeated. They created three versions of this game to see whether intrinsically motivated games would increase learning more than extrinsically motivated games. The three versions were: an intrinsic version which integrated math directly into the game, an extrinsic version which added math problems as separate elements not connected to the game and a control version with no math present. All children improved their division knowledge after playing the game, however students who played the intrinsic version improved the most, evident on a delayed post test. This study highlights the importance of integrating educational content directly into games to provide intrinsic motivation and increase learning. It shows that the careful design of games has important impacts on learning.

Another aspect of using games in educational contexts is the notion of gamification, or adding game-like elements such as points and challenges to activities. Gamification can increase motivation and participation by providing another layer of interest to an activity that both motivates and educates learners (Kapp, 2012). Adding gamification elements also increases problem solving activity in collaborative ways. Kapp (2012) states that those in the field of learning and education must gain knowledge of gamification techniques to improve learning, retention and application of knowledge.

Conclusions

Playing classic games, adapting classic games, designing novel games for specific educational purposes, playing technological games and adding gamification elements to activities are all ways in which we can improve educational activities. However, it is unclear what format of board games is most beneficial to learning. It is also unclear how feasible it is for teachers to integrate technology games into their classroom. The current work focuses on two studies in which the benefits of educational games in the classroom were explored. The first study focuses specifically on the benefits of specifically designed numerical board games in an early childhood classroom and in which format show the strongest benefits on preschoolers early numerical knowledge. The second study explores how a technological game play and game creation tool and framework can be implemented by teachers for use in their classrooms to develop deeper mathematical knowledge as well as computational thinking skills. The first study, including prior research and motivation, will be presented in Part 2 of this thesis. The second study will be presented in Part 3.

Part 2: Study 1: Numerical Board Games in a Preschool Classroom

The first study presented in this thesis focuses on the use of numerical board games in preschool classrooms. We designed our study around prior research on numerical board games, but extended this research to introduce a novel version of a board game that has been previously shown to increase learning, when used in other studies. In our study, we build upon prior research on numerical linear board games as well as embodied cognition to combine what we know to create an embodied, physically active version of traditionally used board games. Chapter Two will cover prior research on board games in preschool classrooms as well as introduce an embodied cognition perspective which we designed our game around. Chapter Three will summarize the specific studies we designed our study around and aim to replicate and explain how the measures in our study have been used previously. Chapter Four will present our study and discuss the design, methods, results and implications.

Chapter Two: Embodied Cognition & Games in Early Childhood

Math Games in Early Childhood

As summarized in Chapter one, games can be effective learning activities in and out of classrooms. More specifically, games have been used in early childhood and have shown to improve early mathematical skills (Siegler & Ramani, 2009), which emerged as the greatest predictor of later achievement (Duncan et al., 2007). Prior research has explored the effects of game playing on different aspects of children's mental abilities. The National Associate for the Education of Young Children (NAEYC, 2002) identified board games as excellent tools to promote an understanding of important mathematical concepts, through social interaction and problem solving and reasoning, skills which were labeled as the heart of mathematics.

One study explored the correlation between game playing in children's homes and their spatial abilities. Newcombe and Sanderson (1993) found a positive relationship between children participating in neutral activities, neither feminine or masculine (such as board games), in their homes and their spatial abilities. This study highlights the natural integration of games into children's home life and shows their positive impact on children's abilities.

Another study explored how different activities affect the development of children's numeracy skills. Young-Loveridge (2004) tested the effectiveness of a program designed to increase number skills of 5-year olds. They found that playing numerical board games, along with reading number stories, were effective ways to increase numeracy skills in young children, specifically those who may be falling behind. The benefits of the program were still evident a year after the program ended.

Peters (1998) conducted a study exploring how math games can promote math learning in preschool. Five year olds played games in the classroom in small groups with parents, who came into the classroom for 8 months. The children in the study were identified as having low-to average number knowledge. They were compared to other children who did not undergo the intervention. The effectiveness of the intervention was evaluated with task-based interviews. Results showed that the largest gains were in tasks that involved enumeration, rote counting, understanding of the number sequence and recognition of number patterns and that children in the intervention group outperformed their counterparts.

A large study of 1540 preschoolers (Dillon et al., 2017) looked at the effects of playing math games on their math skills. Children in the experimental condition played five math games over a period of four months for three hours a week, while those in the control condition followed a typical preschool curriculum. A third active control group played games similar in structure to the math games, but with a social focus, rather than a math focus. Children who played the math games scored higher on tests of mathematical abilities than in the other two groups. This study shows that integration of math games into a current preschool curriculum can improve math abilities.

The importance of teacher and researcher designed games has also been explored with an early childhood population. Wang and Hung (2010) conducted a study in which teachers designed games for their students to play in the classroom with the goal of developing their number sense skills. Teacher designed games are important in that they can be tailored towards each student's levels and learning needs. When played in small groups they also allow for instances of peer tutoring by pairing students of differing levels. Children who played the teacher designed game improved more than students in a control group, who continued regular class instruction, and were also engaged in the game and enthusiastic about playing. Wang and Hung (2010) also claim that these games empowered the teachers to engage in curriculum design, based on teacher reflections.

One aspect of games that could be particularly motivating and engaging to students is the fact that games can be physically active and make use of the whole body. Physically active games extend learning beyond the seats of the classroom and allow students to ground their knowledge with their physical experiences in the environment, making abstract concepts more concrete (Koedinger, Alibali, & Nathan, 2008).

An Embodied Cognition Perspective

Games have been shown to be effective learning activities in preschool classrooms but, beyond game play, some have argued for classroom learning environments to be more embodied and collaborative for students (Abrahamson, 2009; Nardi, 1996). An embodied cognition approach states that how we experience the world around us affects how we think and learn, specifically our cognitive processes (Foglia & Wilson, 2013). Theories of embodied cognition focus on linking full body interaction to content by means of gestures (Barendregt & Lindström, 2012; Howison, Trninic, Reinholz, & Abrahamson, 2011; Johnson-Glenberg et al., 2014), or to follow full-body interaction with learning material (Hatton, Campana, Danielescu, & Birchfield, 2009; Lindgren, Tscholl, Moshell, 2013; Melcer, 2017). Embodied activities give students the freedom to move around their environment and be more physically active, engaged and connected to what they are learning. The goal of embodied activities is to prime students to ground their thinking through object manipulation, action and gesture to make abstract concepts more concrete (Koedinger, Alibali, & Nathan, 2008). One study showed that the use of body based movements and gestures allowed students to act out and become mathematical ideas and helped them reason through geometric proofs (Walkington, Boncoddo, Williams, Nathan, Alibali, Simon, & Pier, 2014). Embodied games also allow students to move beyond a table and chair and to experience the game with their whole body. Games can also take on an embodied form.

In this work we will focus on one framework of embodiment. We will incorporate the design framework for Embodied Learning Games and Simulations (Figure 1) of the five modes of physical embodiment developed by Melcer & Isbister (2016). In a *direct embodied* mode, the learner becomes the manipulative and experiences physical properties of the manipulative, for example becoming a geometric angle and connecting the definition of acute and obtuse. In an *enacted* mode, the learner becomes a vehicle to allow their body to explore the environment, for example, walking along a piano keyboard to explore the relationship between position and pitch. In a *manipulated* mode, the learner uses their senses to explore the manipulative, for example turning the pieces of a puzzle or pattern blocks to find how they fit together. In a *surrogate* mode learners act as a proxy to move another object to explore the environment, for example moving a doll around a dollhouse or moving a game piece along a game board. In an *augmented* mode the learner moves their body to inflict a response in a technology tool, such as when a learner rolls a bowling ball along a virtual lane using a Wii remote. Prior studies have shown that cognition is improved when motion, physicality, and embodiment are incorporated into the learning tasks (Link, Moeller, Huber, Fischer, & Nuerk, 2013; Melcer & Isbister, 2016).

We will explore the different affordances of playing linear board games in either an *enacted* or *surrogate* mode (Figure 1) and how that affects learners' experiences with the environment. We will first try to replicate a previous study (Ramani & Siegler, 2008) on linear board games which were played in a surrogate mode. Then, we will explore how learning gains differ in children who played an enacted version of a colored and numbered linear board game. Prior research has shown that physically active activities increase engagement and that full body interaction with learning material allows students to connect their thoughts and ideas to concrete physical objects in their environment. We question whether full body interaction and physical engagement will affect learning in a linear board game activity. The specific linear board game will be described in the next chapters.

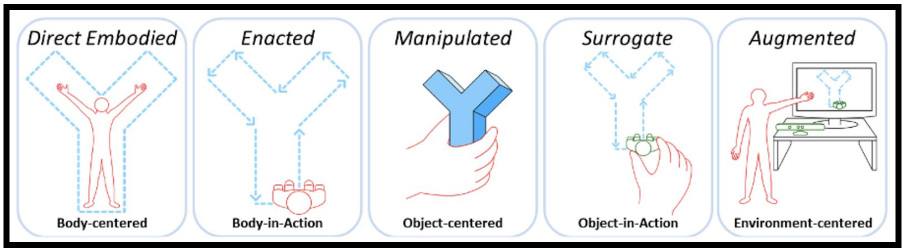


Figure 1: Embodied Learning Games and Simulations developed by Edward Melcer (2017)

Chapter Three: Numerical Linear Board Games & the Number Line Estimation Task.

While games in general have been shown to improve math skills, in particular, numerical linear board games have been shown to improve the numerical skills of preschool and kindergarten aged children (Ramani & Siegler, 2008, Whyte & Bull, 2008; Siegler, 2009; Siegler & Ramani, 2009; Ramani & Siegler, 2011; Ramani, Siegler & Hitti, 2012; Siegler & Ramani, Laski & Siegler, 2014). The effects that linear board games have on children's numerical knowledge is oftentimes measured using a number-to-position number line estimation task (Siegler & Booth, 2004) which has implications on future success. In this task, the participant is asked to estimate the location of a given number on a blank number line (other than that the end points are numbered). It may be numbered 0-10, 0-100, or 0-1000. For example, a child given a blank number line labeled with "0" at one endpoint and "10" at the other endpoint may be asked, "where do you think 7 belongs on this line?" Children represent the magnitudes of numbers in two different ways when completing this task. One common representation is linear and the other is logarithmic. In a logarithmic representation the estimates follow a logarithmic function where the distances between the smaller estimates are exaggerated and the distances between the larger estimates understated. In a linear representation the estimates follow a linear function of the actual magnitude and estimates increase linearly along the actual values. Children's representations change with age and with the number range represented. As children get older their estimates become more linear. Reliance on a linear representation is an important factor in numerical knowledge development (Siegler & Ramani, 2008) and correlates strongly with math achievement scores (Siegler & Booth, 2004). Based on evidence of the importance of linear representations on the number-to-position number line estimation task, it is important to provide activities which support in children's development of these linear representations.

Linear board games are an activity commonly used to improve these representations. Ramani and Siegler (2008) conducted a study to examine the effects of playing linear board games on preschoolers performance on the number line estimation task as well as their performance on measures of counting, numerical identification and numerical magnitude comparison. Children completed a version of the number-to-position number line estimation task in which they indicated where they believed a given number belongs on a blank number line labeled 0-10. They also completed a task where they identified the arabic numerals 1-10, chose which of two numbers was larger, and counted. Participants were 124 preschool children from Head Start programs ranging in age from 4 years 1 month to 5 years 5 months. Their study included two conditions of board game type. The first board game design included 10 colored squares layed out linearly. Children moved one or two squares at a time, as indicated by a spinner, until they reached the end. The second board game was similar in all aspects except instead of colored squares, the squares were numbered 1-10 and the spinner indicated 1 or 2 spaces rather than colors. Children met with researchers for four 15-20 minute sessions over two weeks, playing their assigned game 20 times. Results from this study showed that children in the numbered board game group's estimates on the number line task became more linear after playing the game, whereas the estimates of the children who played the game without numbers did not become more linear. Children in the numerical board game group also improved on the other three tasks. This supports the notion that playing numerical linear board games can lead to improvements in the linearity of children's number magnitude estimates.

Elofsson, Gustafson & Samuelsson, 2016 conducted a similar study in which they compared the effects of a linear number board game, a circular number board game and nonlinear numerical activities on the development of number knowledge and early arithmetic (number line estimation, counting, naming Arabic Numbers and arithmetic calculation) in 5 year old preschool children. They found that children who played the linear number board game improved in their performance on the number line estimation task, while those in the other conditions did not, supporting Ramani & Siegler, 2008. Those children in the linear number board game group also improved in their calculation performance.

This prior work has been extended to show that game boards must include numbers (Ramani & Siegler, 2008), and that linear, not circular games are most beneficial (Siegler & Ramani, 2009; Whyte & Bull, 2008). This study was also extended to explore the effects of the game in a small group setting led by the classroom teacher or paraprofessional in Head Start programs (Ramani, Siegler & Hitti, 2012). Playing the game as a small group learning activity promoted children's number line estimation. This extension showed that the games can be an effective classroom activity in the absence of researchers. Siegler, 2009, also showed that this game can be used to decrease the gap between low-income children and their affluent peers by leading to improvements on numerical magnitude comparison, number-line estimation, counting and numerical identification. Ramani & Siegler, 2011, further extended this result by comparing the effects of the game between low-income and middle-income preschoolers. Playing the linear numerical board game again produced greater learning gains, as measured by number line estimation, magnitude comparison, numeral identification, and arithmetic, than other numerical activities. Children who began with lower knowledge generally learned more, and children from low-income backgrounds learned just as much or more than those from middle-income backgrounds who had similar initial knowledge. With the abundance of prior work it is clear to say that playing linear board games in preschool leads to improvements on children's numerical knowledge.

Specific Study To Be Replicated

Ramani & Siegler (2008). Ramani and Siegler, 2008, conducted a study to examine the effects of linear board games on preschoolers performance on four numerical tasks; numerical magnitude comparison, number line estimation, counting, and numeral identification. Their previous study had only included the number line estimation task so they wanted to see if the game has more generalizable effects.

Methods. They included 124 preschool children in their study, ranging in age from 4 years 1 month to 5 years 5 months from 10 Head Start programs. Each participant was assigned to play one of two versions of a linear board game. The first was a color board game with 10 squares arranged horizontally with start on the left and end on the right. The second board game was identical to the first, except it included numbers 1-10 listed consecutively on the spaces. Each game included a spinner, with either numbers 1 and 2 to match the number game or colors which matched the game board spaces colors. Children either moved the number of spaces shown on the spinner or moved to the next closest color that matched the spinner.

Children met individually with researchers for four 15-20 minute sessions over two weeks. They played one of the two games 20 times, each game lasting 2-4 minutes. They were told that whoever reached the end first was the winner. Children were also told to say the number or color of the space they were on as they moved their playing piece across the board.

Measures of Numerical Knowledge. This study included four measures of numerical knowledge as a pre- and post-test, and also included a follow up post-test, given 9-weeks later. The first task was *counting*, where children were asked to count from 1 to 10 and their highest counted number was recorded as their score. The second task was the *number line estimation* task. Children were presented with 18 number lines labeled 0 and 10 at each end respectively and asked to place the number 1 through 9, twice each in a random order. All numbers 1 through 9 were presented before each was presented a second time. The linearity and slope of the estimates were examined. The third task was a *numerical magnitude comparison* task. Children were presented with 18 number pairs (of 36 possible) of numbers 1 through 9 and asked to identify which number was larger. The total number correct was used as the score. The final task was a *numerical identification* task where children were asked to identify the numbers 1 through 10, shown in a random order. The number identified correctly was used as the score.

Results. The authors used a median split to separate participants into a younger and older group to look at the effects of the intervention on different ages. The authors first ran a 2 (age) × 2 (condition) × 3 (time: pre-test, post-test, follow up) repeated measures MANOVA on the five measures of numerical knowledge (number line estimation in two ways). There were significant effects of age, condition, time and a condition × time interaction. To interpret and better understand the results they conducted univariate analyses for each task and used bonferroni corrections for the post hoc tests.

For the numerical identification task there were significant effects of age, condition, session and a condition × session interaction. Children who played the number board game made significant gains in the numerical identification scores where those who played the color board game did not.

For the numerical magnitude comparison task there were significant effects of age, condition, session and a condition × session interaction. Similar to the numerical identification task, children who played the number board game made significant gains in the magnitude comparison scores where those who played the color board game did not.

The authors found similar results for the counting task in that children who played the number board game made significant gains in the counting scores where those who played the color board game did not. The authors also looked at the percentage of children who could count perfectly to 10 in each group at pre- and post-test. There was no difference between the percentage who could count to 10 in the color and number game groups at pretest but at post-test more children in the number group could count to 10.

To examine the results of the number line estimation task the authors first calculated the percent absolute error of the estimates. Similar to previous analyses there were differences in that the children who played the number board game's absolute error decreased whereas those who played the color board games's absolute error showed no change.

Next, the authors looked at the linearity of the estimates. They found that the linearity of the group median estimates increased in those who played the number board game but not for those who played the color board game. The authors also looked at the mean linearity of individual children's estimates which showed an increase in linearity in those who played the number board game but not in those who played the color board game.

Next, the authors looked at the slope of the estimates. They found similar results in that the slope of the group median estimates of those who played the number board game increased while the slope of the group median estimates of those who played the color board game did not. When looking at individual children's estimates they found a similar pattern.

Summary of the study. Overall, the study showed that when children played a numerical linear board game they improved on four measures of numerical knowledge while those who played a colored linear board game showed no improvement on the tasks. Our study aims to replicate previous findings and follows similar design and approach to analyses as Ramani and Sielger (2008). However, our study differs in major ways. 1) Along with the table top colored and number board games we introduce full body, walkable versions of the smaller games based on an embodied cognition perspective. 2) Our participants played their designated game a total of 10 times, as opposed to the 20 times played in previous studies. We observed a shorter attention span, so we limited games to 10 times total. 3) We had children play the game in groups of 2, with a researcher facilitating game play. It is rare that children play games 1 on 1 with an adult in a preschool setting so we wanted to make the setting more authentic as well as encourage cooperation and peer communication.

Chapter Four: Our Study

Participants

Participants were 40 children (47.5% female) from a Massachusetts preschool, ranging in ages from 3 years 1 month to 5 years 6 months (*M* = 4 years 5 months, *SD* = 8.13 months). Consent forms were provided to parents and guardians and they gave consent for their child to participate in the study. Participation was voluntary and children were given stickers for completing pre- and post- assessment tasks.

Procedures

We included four game board conditions in our study. Mirroring Ramani and Siegler (2008) the first two board games are played in the surrogate mode on a numbered or colored game board. The other two game boards also include a colored and a numbered version but are played in an enacted, full body mode where children walk along the game board.

Participants were randomly assigned to one of four game board conditions, with *n*=10 in each condition. Preschool children met with a researcher four times during a four-week period with approximately one week between each session. During the first and last sessions participants completed pre- and post-assessments of numerical knowledge. During the other two sessions each participant played their designated version of the game a total of 10 times. Each game lasted 3-5 minutes.

Children played the game in pairs with the researcher as a facilitator to assist the children during game play. At the beginning of each game, the researcher told the children that they would take turns spinning the spinner and moving their designated spaces until both players reached the end. The game ended when both children reached the end of the game board. There were no specified winners to the game in an effort to increase support and collaboration between the children playing the game. Children alternated who would go first, often facilitated on their own.

If the children played the color-only version, regardless of the mode of embodiment, they moved to the nearest color that matched their spin. The researchers directed the children to say aloud the color of the squares as they moved. If they made a mistake, the researcher said the correct response and asked the children to repeat their moves.

If the children played the number version, they moved the number of spaces that they spun. The researcher instructed them to say the number of the space they were on as they moved. For example, if they were on a “6” space to start and spun a two, they said, “seven and eight”. If children made an error in naming or could not name the number, the researcher said the correct responses and asked the children to repeat their move. Children acted as the playing pieces in the larger, enacted versions and children chose a color playing piece (taken from the board game-Sorry!) to use in the table top, surrogate versions.

Board Game Materials

Surrogate Board Games. The typical tabletop game board was composed of ten spaces, arranged horizontally with “start” at one end and “end” labeled at the other end. The difference between the two game boards is that one has numbers 1-10 on the spaces and the other has two colors arranged in an abab pattern. Both games were the same size (Figure 2.)

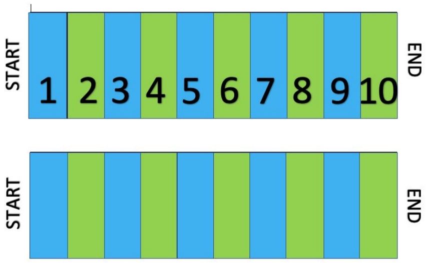


Figure 2: Board games used for surrogate mode.

Enacted Board Games. The enacted version of the board game was composed of ten 12×12inch squares. The individual squares were larger on the enacted boards than the surrogate boards as to allow room for children's feet as they move across the board. In all other aspects, the structure and design of the two larger game boards are almost the same as the two smaller version, with two exceptions. First, the start and end labels were not on the enacted versions. Second, the enacted version has square shaped spaces to allow for space for the children's feet. (Figure 3.)

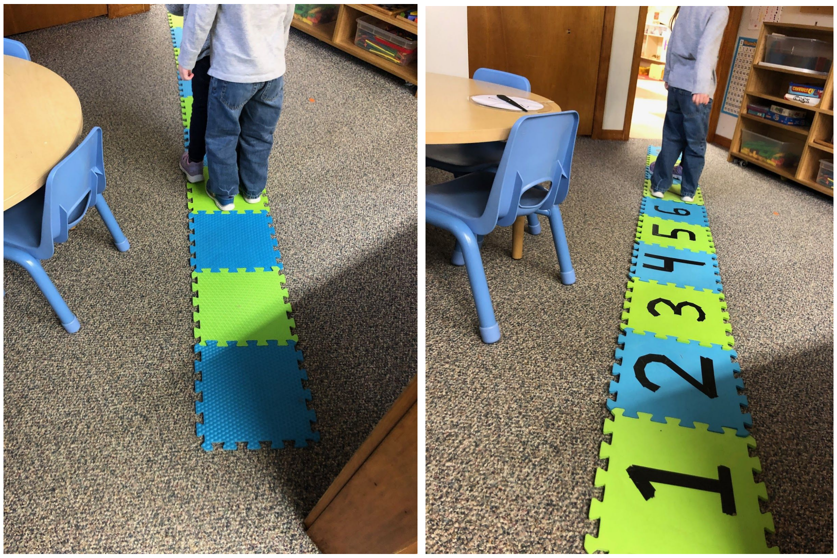


Figure 3. Children playing the enacted game versions in their classroom.

Spinners. Two round spinners were used for game play, halved by the circle's diameter with a black hand anchored at the center. For the versions of the games that include numbers, a colorless spinner was used with an Arabic numeral 1 or 2 on each semi-circle. In the color games, half of the circle was colored green and half was colored blue, matching the spaces on the game boards. (Figure 4.)

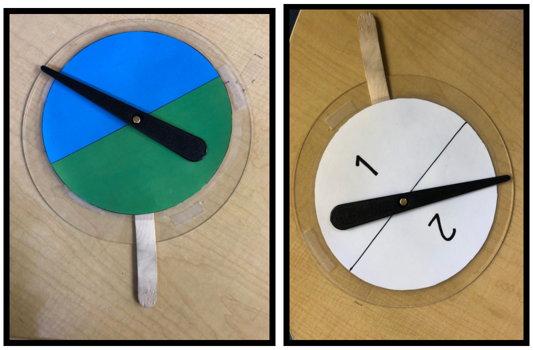


Figure 4. Spinners used in the board games

Measures of Numerical Knowledge

Children completed four measures of numerical knowledge at the beginning of the first session and at the end of the last session. The tasks were given in the following order to each child: counting task, numerical identification, magnitude comparison, and lastly, the number line estimation task. These tasks are all identical to those used by Ramani and Siegler (2008) in previous work with the exception of the number line estimation task which will be explained further. Children were tested twice on each task, as opposed to just two twice on the number line estimation task, and we took the average of both trials on each task.

Counting Task. During the counting task, children were instructed to count aloud from 1 to 10. Children received points from 1 to 10 based on the highest number correctly reached. The researcher recorded the highest number correctly counted. The highest number correctly counted was used as a dependent variable in analyses.

Numeral Identification. During the numeral identification task, children were presented with 10 cards, each displaying one Arabic numeral from 1-10. The researcher held up the cards in random order and asked the child to identify the number on it. The total number of correct answers the child gave was recorded. The total number of correct answers was used as a dependent variable in analyses.

Numerical magnitude comparison. Children were verbally and visually presented with 18 pairs of numbers (out of 36 possible), each number being from 1-9. Children were asked to identify which number was the larger of the pair. The numbers were presented in a randomized order to each participant. Answers were marked as correct and incorrect and were recorded on a scoring sheet. On their second trial of 18 pairs, children saw the other 18 possible pairs, so all number pairings were seen by all participants. However, to keep analyses similar to previous analyses used, the average score of the two trials was recorded. The percentage of correct answers (out of 18) was used as a dependent variable in analyses.

Number Line Estimation Task. During the number line estimation task, children were presented with 9 sheets of paper, given one at a time. Each sheet displayed a 10-inch, unmarked number line starting with 0 and ending with 10. Children estimated the location of numbers one to nine. On each trial, the researcher said, " if this is where 0 goes and this is where 10 goes (while pointing at the numbers), then where does N go?" Then children were asked to mark its location on the line. In the original study by Ramani and Siegler (2008), an Arabic numeral from one to nine was printed 2 cm above the center of the line. For our study, we did not place the numerals above the center of the line to avoid bias toward placement in the center of the line. Instead we verbally presented the number to avoid any placement biases.

To analyze performance on this task we used two different measures. We looked at both the linearity and slope of the average of participants estimates. It is important to look at both of these measures as they provide different information about the accuracy of the estimates. For example, a child's estimates could have a slope equal to 1, but the linearity may be less than one, indicating a wider range of estimates. Similarly, a child's estimates may be perfectly linear, with $R^2 = 1$, but with a slope that does not equal 1. For a child to have perfect estimates, the linearity and slope would both equal 1.

We also looked at the percent average error of the estimates. A lower error indicates more accurate estimates. Since lower scores indicate higher accuracy, as opposed to higher scores indicating higher accuracy on all other tasks, this measure was not included in the MANOVA but we did analyze this measure individually.

Results

Following the approach to analyses used by Ramani and Siegler (2008), we first looked at the multivariate effects of condition and session (pre and post test) on five numerical knowledge measures across four tasks. A 4 (Condition) × 2 (Session) repeated measures MANOVA on the five measures of numerical knowledge revealed no main effect of condition, $F(15,89) = 1.48$, $p = .13$, $\eta_p^2 = .19$, or session, $F(5,32) = 1.48$, $p = .23$, $\eta_p^2 = .19$. There was also no Session × Condition interaction, $F(15,89) = 1.28$, $p = .23$, $\eta_p^2 = .16$. We then ran univariate tests for each measure, to mirror the analyses run by Ramani and Siegler (2008) and to explore any effects on individual tasks. A 4 (condition) × 2 (session) repeated measures ANOVA was run for each of the 5 measures of numerical knowledge, after conducting a one-way ANOVA to see if there were differences between conditions at pre-test.

Numerical Identification Task. A one-way ANOVA revealed no effect of condition on numerical identification score at pretest, $F(3,36) = 1.67$, $p = .19$. A 4 (condition) × 2 (session) repeated measures ANOVA revealed main effects of session, $F(1,36) = 4.61$, $p = .04$, $\eta_p^2 = .14$, and a Session × Condition interaction, $F(3,36) = 5.07$, $p < .01$, $\eta_p^2 = .30$, but no main effect of condition. Overall, children showed improvement from pretest ($M = 7.30$, $SD = 3.01$) to posttest ($M = 7.50$, $SD = 3.07$), and the effect of session was mainly driven by the surrogate number board game condition. Post hoc tests with Bonferroni adjustment showed that children who played the surrogate number board game improved from pretest ($M = 7.5$,$SD = 2.12$) to post test ($M = 8.4$, $SD = 2.38$) , $p < .01$, whereas children who played the other game versions did not improve on the numeral identification task, p > .xx (Figure 5.)

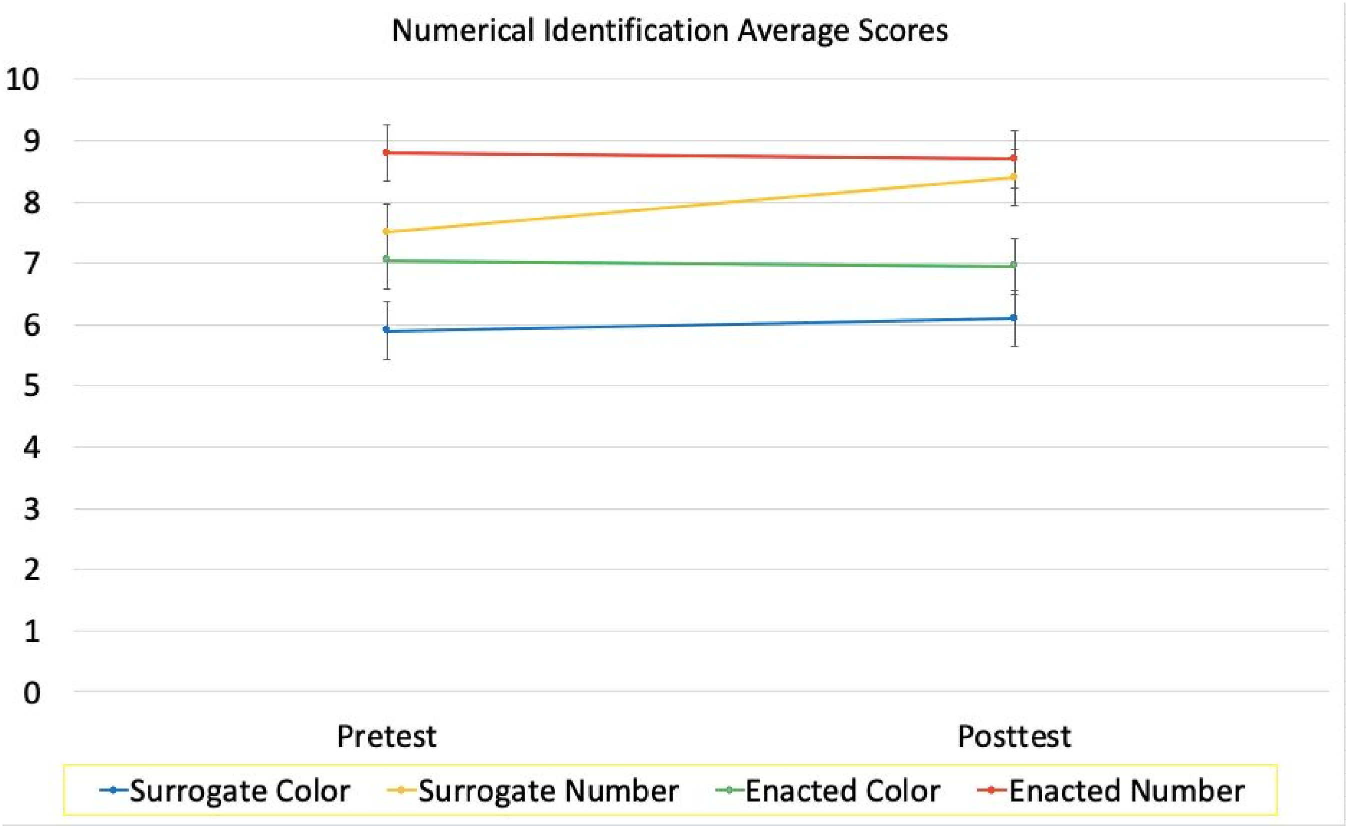


Figure 5. Mean scores of the Numerical Identification Task

Counting Task. A one-way ANOVA revealed no effect of condition on counting score at pretest, $F(3,36) = 1.33$, $p = .28$. A 4 (condition) × 2 (session) repeated measures ANOVA revealed no main effects of session, $F(1,36) = .28$, $p = .61$, $\eta_p^2 = .01$, and condition $F(1,36) = 2.85$, $p = .05$, $\eta_p^2 = .19$ and no session × condition interaction, $F(3,36) = .18$, $p =. 91$ $\eta_p^2 = .01$.

(Figure 6.).

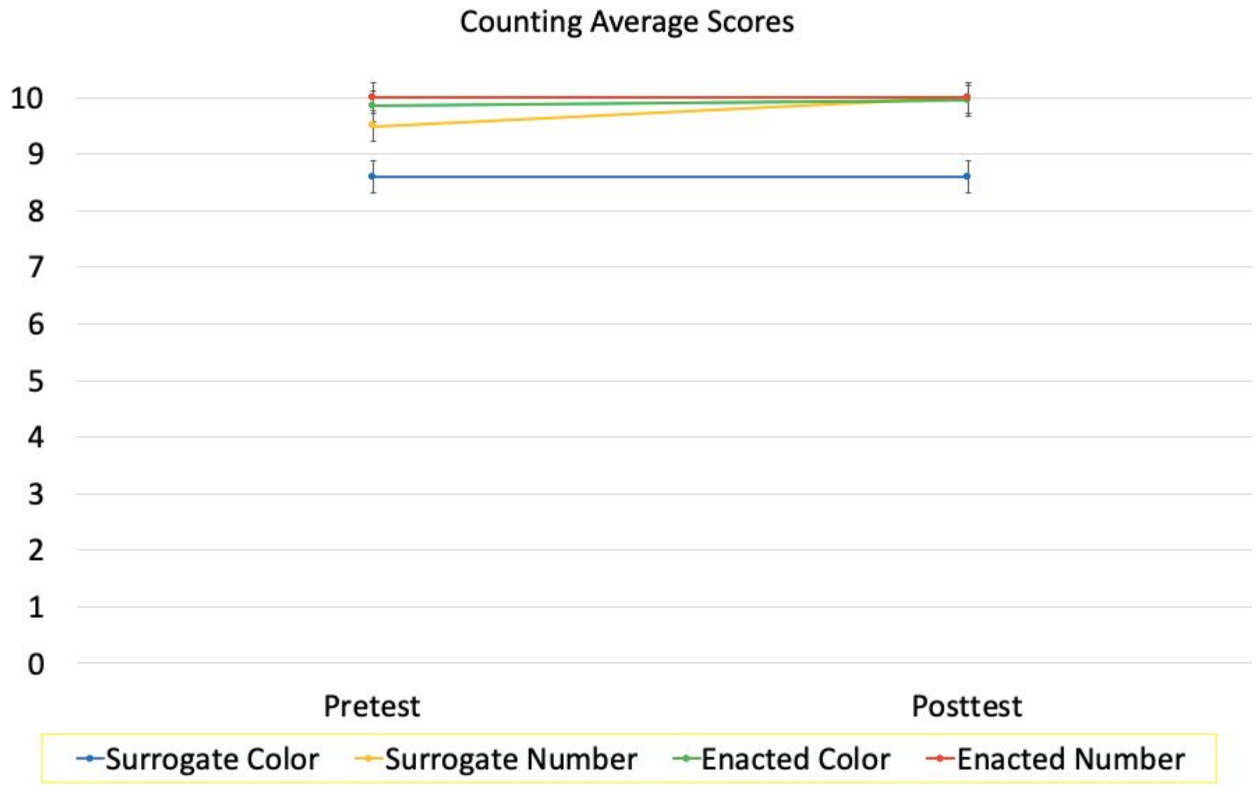


Figure 6. Mean Scores of the Counting Task

Numerical Magnitude Comparison Task. A one-way ANOVA revealed no effect of condition on pretest score, $F(3,36) = 1.19$, $p = .33$. A 4 (condition) × 2 (session) repeated measures ANOVA revealed no main effects of session, $F(1,36) = 1.40$, $p = .25$, $\eta_p^2 = .04$, condition $F(1,36) = 1.00$, $p = .41$, $\eta_p^2 = .08$ and no session × condition interaction, $F(3,36) = .49$, $p = .69$ $\eta_p^2 = .04$. (Figure 7.).

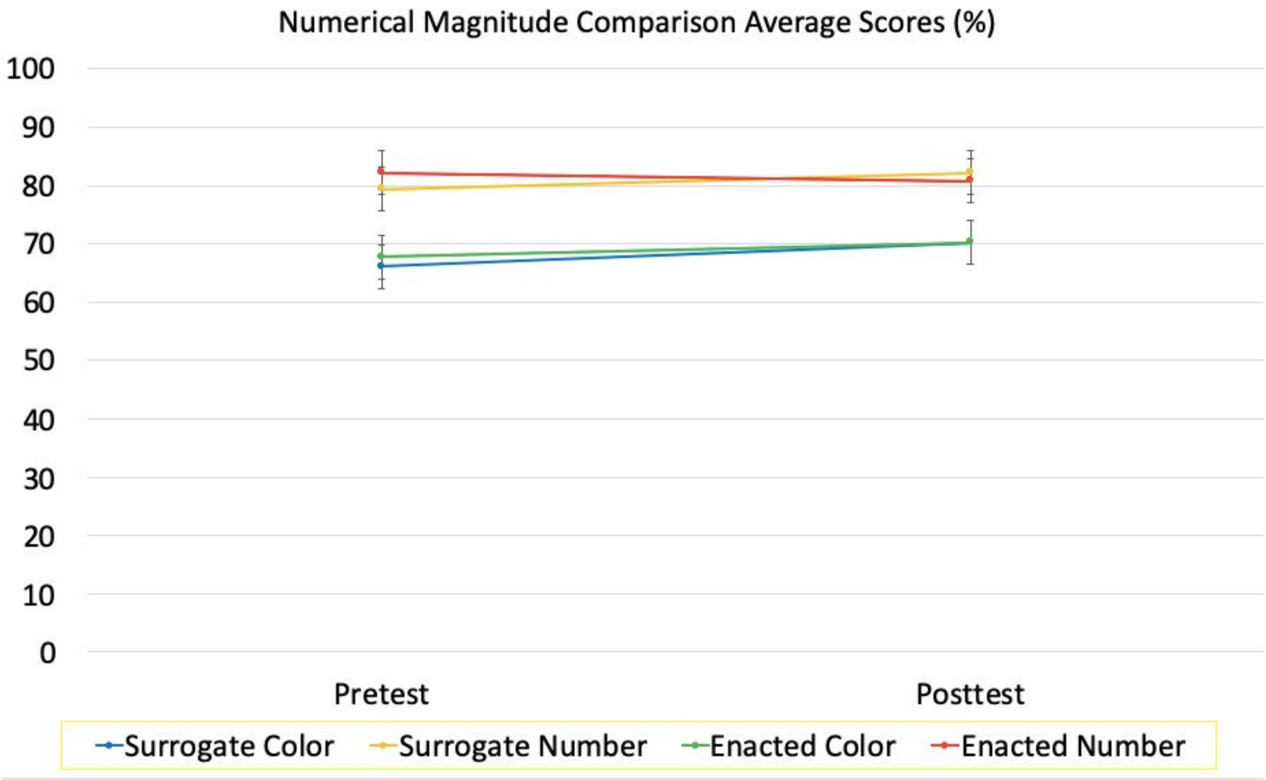


Figure 7. Mean scores of the Numerical Magnitude Comparison task

Accuracy of Number Line Estimation Task. We obtained an accuracy score for the number line estimation task by calculating participants percent average error for their estimates. Lower scores indicate lower error and therefore more accurate estimates, therefore this measure was not included in the MANOVA. A one-way ANOVA revealed no effect of condition on pretest score, $F(3,36) = .61$, $p = .62$. A 4 (condition) × 2 (session) repeated measures ANOVA revealed no main effects of session, $F(1,36) = .24$ $p = .63$, $\eta_p^2 = .01$, condition $F(1,36) = .45$, $p = .72$, $\eta_p^2 = .04$ and no session × condition interaction, $F(3,36) = .60$, $p = .62$ $\eta_p^2 = .05$. (Figure 8.).

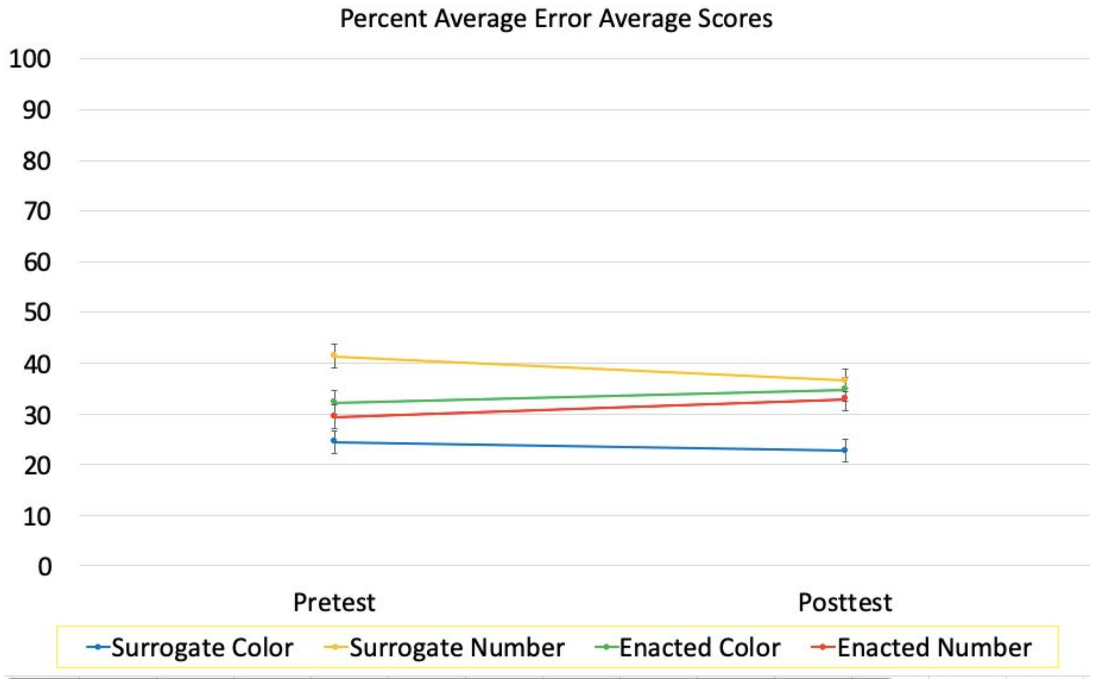


Figure 8. Mean percent average error for the Number Line Estimation Task

Linearity of Number Line Estimation Task. A one-way ANOVA revealed no effect of condition on pretest score, $F(3,36) = 2.10$, $p = .12$. A 4 (condition) × 2 (session) repeated measures ANOVA revealed no main effects of session, $F(1,36) = .01$ $p = .96$, $\eta_p^2 = .00$, condition $F(1,36) = 2.02$, $p = .13$, $\eta_p^2 = .15$ and no session × condition interaction, $F(3,36) = 1.4$, $p = .26$ $\eta_p^2 = .11$. (Figure 9.).

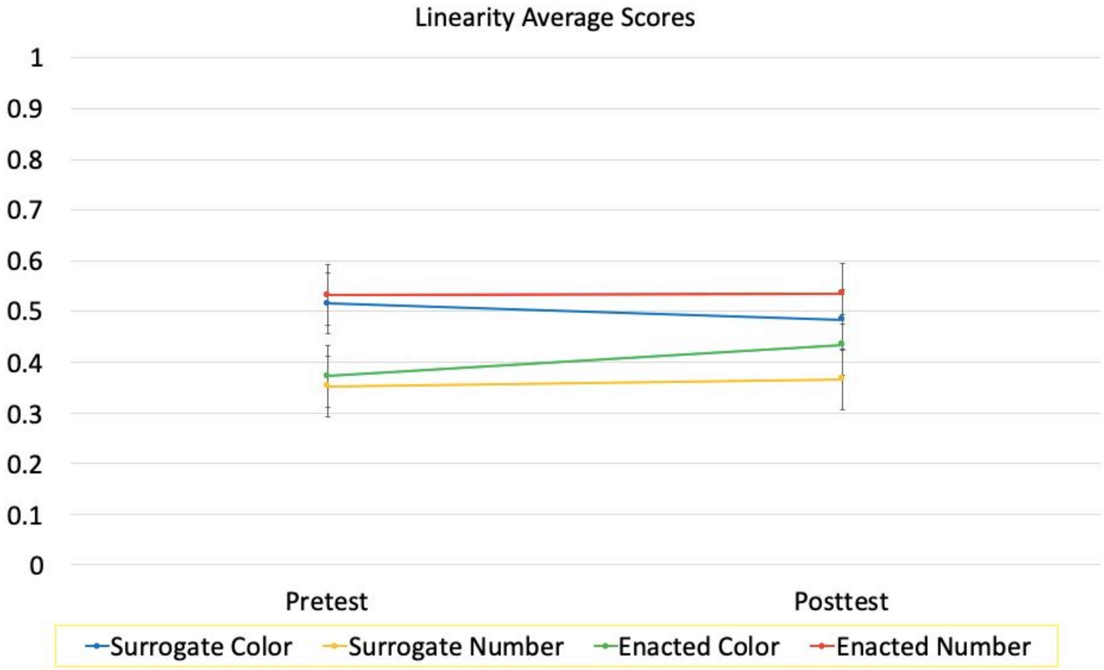


Figure 9. Mean Linearity for the Number Line Estimation Task

Slope of Number Line Estimation Task. A one-way ANOVA revealed no effect of condition on pretest score, $F(3,36) = 1.37$, $p = .62$. A 4 (condition) × 2 (session) repeated measures ANOVA revealed no main effects of session, $F(1,36) = 8$ $p = .38$, $\eta_p^2 = .02$, condition $F(1,36) = .82$, $p = .50$, $\eta_p^2 = .06$ and no session × condition interaction, $F(3,36) = .73$, $p =.54$ $\eta_p^2 = .06$. (Figure 10.).

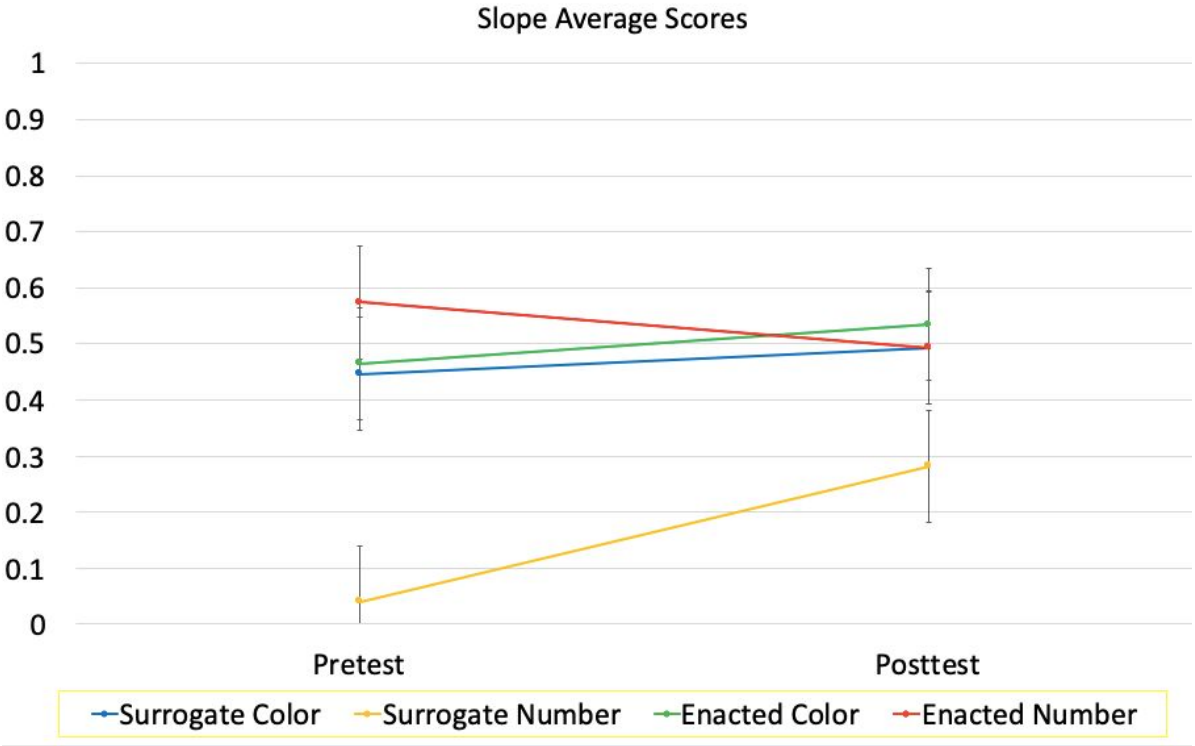


Figure 10. Mean Slope for the Number Line Estimation Task

Discussion

Our results of the numerical identification task support the results found by Ramani and Siegler (2008) in that children who played the numerical board game improved where those who played the color board game did not. However, beyond this task, we found a lack of significant results and are unable to either support or refute the results found by Ramani and Siegler (2008). While we found no significant affordances to playing the enacted version of the game, a larger sample is needed to examine any true differences. Anecdotally, children were engaged when playing the enacted version of the game and were able to participate in a gross motor activity while playing the game while children playing the surrogate version did not experience the gross motor aspect.

Limitations

The main limitation in our study is the small sample size. We were only able to run 40 participants total, leaving only 10 to each experimental condition. This limited our ability to find significant differences between the groups.

Another limitation is that children performed at the ceiling for some tasks which again limited our ability to find improvements. For the counting task, 35 out of 40 participants correctly counted to 10 at pretest and 36 out of 40 at post test across all conditions.

Further, while there were no significant differences between the groups at pre test on any of the tasks, there were definitely differences. A larger sample may be able to detect significant differences or even out the differences between groups.

Future Work

We are planning on collecting more data on this project in the Summer of 2020. We aim to run 120 participants giving us 80% power to detect an effect size of f=.15 at an α=.05.

Part 3 Study 2: Integrating Technology into the Classroom Through Games

The second study presented in this thesis focuses on the implementation of technology-augmented games as learning activities to promote math and computational thinking (CT) skills. We introduce a professional development program aimed to teach teachers and students how to play games as well as how to create games using a technology-based game editing tool. Through game play, students learn math skills, and through game creation, students learn problem solving, math and CT skills. We describe a 14-week professional development program in which mathematics and STEM middle school teachers played, designed, tested, and implemented novel mathematics games with their own students. Teachers first played mathematics games on mobile devices, then designed and programmed their own games using the Wearable Learning Cloud Platform, on computers. Teachers then introduced this process and technology to their classes by having students play the teacher-created games, and later designing and programming games of their own. Our evidence suggests that the PD framework is effective, as students and teachers engage in game play and create games using the platform.

In this section, there are five chapters. Chapter five will cover prior research on using technology-augmented/based games in the classroom, as well as prior research on game creation. Chapter Six will describe the online game editing and playing tool used in the workshop. Chapter Seven will cover the design and implementation of the professional development worksop. Chapter Eight will discuss results from that workshop including learning gains, game products and survey responses. Chapter Nine will discuss future directions and plans. The contents of chapters six, seven, eight and some of chapter nine were taken from a manuscript under review (Smith, Harrison, Ottmar, & Arroyo, 2020.) and written in collaboration with Avery Harrison, Erin Ottmar and Ivon Arroyo.

Chapter Five: Technology Based Games

Technology-Based Games

CT is described as formulating problems and realizing solutions that can be implemented with technology (Wing, 2006; 2010) and has been identified as an important set of skills for today's students to have (Weintrop et al., 2016). CT skills include abstraction, pattern recognition, problem decomposition and error detection (Grover & Pea, 2013). Some argue that CT is a universally applicable set of skills that everyone, not just computer scientists, should have, and that it is a new basic skill which is used in most fields (Weintrop et al., 2016). As this new skill is becoming increasingly important to have in our ever changing society, it is important that students have opportunities to learn CT skills which they can apply in different disciplines (Guzdial, 2008).

So far we have covered many different types of games, but another aspect of games is their use of technology. As technology is becoming more commonplace, economies and societies are shifting to capitalize, depend and focus on it. Naturally, technology has also moved into the classroom, both as a tool used to help teachers teach and students learn, but also as its own content to be learned. Games can be used in classrooms to teach technology through game creation, and technology can also be used in the classroom to play games.

Some of the skills that students may gain through the game creation process make up the skills that lay the foundation for CT. With the rising significance of CT, it is important for researchers and educators to develop activities to help students acquire these skills.

Technology-based games commonly used in middle school STEM classrooms as effective learning tools. Students can learn multiple different skills by playing technology-based games. Children play games and complete learning activities using materials such as computers, laptops or tablets. For instance, Kebritchi, Hirumi and Bai (2010) conducted a study to test the effectiveness of a series of math computer games called DimensionM™. They had high school students play different games within DimensionM™. The authors found that students who played the computer games scored significantly higher on a district-wide math benchmark exam than students who didn't play the games.

Another example is *Zoombinis,* a popular learning game in which students develop CT skills. In *Zoombinis,* players complete challenging puzzles as they take characters on a journey toward safety. As students completed these puzzles and played *Zoombinis,* they used implicit CT skills such as problem decomposition, pattern recognition, abstraction and algorithm design. Through playing games like *Zoombinis*, some students may display their knowledge through these game-based contexts, where they may have trouble displaying what they know on a traditional text. In this case, an educational technology game is a window into what students are thinking as well as a place where they can practice and develop these skills. One study (Rowe, Asbell-Clarke, Cunningham & Gasca, 2017), showed the abilities to measure CT skills within the game *Zoombinis*, providing insights into students' knowledge of CT as they play games.

Scratch (Resnick et al., 2009) is another widely used computer program to help students develop concepts of computer science. *Scratch* is a visual programming environment with millions of users and created projects. Visual programming languages like *Scratch* are promising ways in which students can learn computer science and CT skills. One study showed that middle-school students learned different computer science concepts, such as initialization or assigning initial values to variables, through playing with *Scratch* for one school year (Meerbaum-Salant, Armoni & Ben-Ari, 2013).

However, computer-based learning technologies limit students to a seat at a computer. The increase in the use of mobile technologies have helped in making technological educational activities embodied in that students can carry or even wear these technologies and engage with them as they move around their environment (Johnson, Pavleas & Chang, 2013; Howison, Trninic, Reinholz & Abrahamson, 2011). A growing body of research has shown benefits of using mobile technologies to support learning through game play and game creation. Arroyo, Micciollo, Casano, Ottmar, Hulse, and Rodrigo (2017) found that playing physically active, embodied, math games using mobile technologies improved students' scores on a geometry and math assessment developed from standardized test questions from pre- to post-test compared to students who received typical lectures. This study shows the effectiveness of using mobile technology to promote active participation in games to increase learning.

Creating Games

In addition to playing games and interacting with technology, creating games has also been shown to benefit student learning. Based on constructionist theory, which states that students can learn by making (Papert, 1991), it has been shown that students can learn problem solving skills by going through the game-making process. Students learn to plan, design and overcome challenges as they create games. While most research about creating games focuses on how students develop programming abilities (Howland & Good, 2015; Robertson & Good, 2005), students may benefit in other ways such as developing creativity, critical thinking and problem solving skills (Overmars, 2004; Korte, Anderson, Pain, & Good, 2007; Dalal, Dalal, Kak, Antonenko & Stansberry, 2009). The game creation and programming process requires students to understand the content of their game, and allows them to teach and communicate the content in their own way. This process allows students to engage in deeper thinking about the content in their games as well as overcome and learn from the challenges of creating a game and going through the design process.

Creating games is a well documented activity to integrate CT into the classroom. In a past study, older children created a computer-based video game to help teach fractions to younger elementary school children (Kafai & Resnick, 1996). Through this activity, students learned about the design process and reflected on this process while developing aspects of CT skills. Students learn valuable skills through creating games such as creativity, critical thinking and problem solving skills (Dalal, Dalal, Kak, Antonenko, & Stansberry, 2009; Korte, Anderson, Pain, & Good, 2007; Overmars, 2004). Through game creation, students are able to master the educational content of their game as they have to teach it to others. Students also have opportunities to develop the CT skills which are needed to effectively design a game which can be played in the classroom.

Professional Development for Game-Based Technology Integration in STEM Classrooms

As technology is becoming a bigger part of our lives everyday it is important to teach our students CT skills so that they are able to interact with technology. However, since CT is a newer skill, teachers may not be prepared to incorporate CT practices into their teaching. As teachers begin to incorporate technology into their practice more often, they also need to focus on incorporating CT. Lockwood and Mooney (2017) stated that teachers would benefit by having guidelines to follow and more detailed lesson plans and curriculum on CT to help them incorporate these skills in their classrooms.

There is now an increasing need to provide professional development opportunities to both math and STEM teachers to give them guidance on how to incorporate CT skills into their classrooms. Math teachers are a natural avenue to teach these skills since mathematics and computer science often overlap and math problems are naturally set up in ways that afford CT aspects. In order for teachers to be able to teach these skills to their students they first need to have the knowledge themselves. Prior research has shown that the relationship between teachers, curriculum resources and technology are influential in how curriculum is implemented in classrooms. Teachers differ in how they will adopt and implement curriculum based on their own knowledge and the quality of curriculum materials they receive. There is a crucial three-way relationship between teacher knowledge, pedagogy and technology which affects how technology is integrated into instruction (Mishra & Koehler, 2006). It is important to take into account different teacher knowledge bases and teacher resources when designing technology curriculum and professional development programs.

A high quality professional development program requires the following aspects: 1) an emphasis on core content, 2) active learning, 3) coherence, 4) sustained duration, and 5) collective participation (Desimone, 2001; 2009). In a professional development program, teachers should first experience activities that increase their knowledge and skills as well as change their beliefs (Desimone, 2009). Teachers can then use their new knowledge, skills and beliefs to change their instruction and classroom practices. As teachers change their instruction, this will ideally lead to changes in student behavior and learning. An important aspect to incorporate technology and CT into classrooms is to understand that in order for students to learn and practice these new skills, teachers must learn and practice them first.

This project introduces a new approach for teaching teachers how to integrate CT into STEM education and incorporate technology based math games into their instruction. Through the Game Play and Design Framework, teachers and students both play mobile technology-based math games to deepen their knowledge of math concepts, and create novel games through a visual programming language to engage with CT concepts.

Chapter Six: The WLCP

The tool used in the professional development program is called the Wearable Learning Cloud Platform or WLCP and was developed at WPI by students and researchers. The Wearable Learning Cloud Platform (WLCP; wearablelearning.org) (Arroyo et al., 2017; Micciolo, 2018) is a web-based technology tool that allows users to both *create* and *play* original, active games for STEM learning with mobile devices. Users are able to create accounts and access the WLCP in three different roles to explore both game play and game creation: Game Players, Game Editors, and Game Managers. The WLCP was designed as a platform to play and create games for teachers and students. To that effect, rather than necessitating that schools download their own instance of the platform, users can log into the WLCP for free on any web browser on most devices, including desktop computers and smartphones. This accessibility is in line with the mission of the WLCP to provide all students with opportunities to learn through game creation and game play.

Game Players. Students and teachers can use the WLCP to play existing games in their classrooms (Figure 11). The WLCP hosts a small library of existing games that users can play when they log in as Game Players. The platform provides a means of playing existing games and testing created games by serving them to smartphones. When users login as Game Players, they are able to access public games and those that they or their classmates have created. Students can also play games assigned by their teacher as class-wide activities.

Figure 11. The WLCP serves games to smartphones and wearable devices, allowing students to play active games in their own classrooms.

Game Editors. When users log into the WLCP as Game Editors, they have full access to the user-friendly, visual drag-and-drop game editor to create and refine games to be played on mobile devices (Figure 12). The WLCP is designed for programming novices so that middle and high school students are able to effectively use the game editing platform to create games with a wide variety of content, multiple levels and players. Teachers and students first plan out and design the behavior of their mobile devices as finite state machines on paper, then transfer them into our novel visual programming language, which assumes no prior programming knowledge. The first "state" in their design corresponds to the first message that their device displays when it is turned on. As students program their games, they specify states by choosing every behavior of the mobile device, including the text to be displayed on the screen (a question, hint, or welcome message) as well as lights, colors, buzzers, images, sounds and vibrations of each phone/smartwatch. Middle school students (and their teachers) design and enter what their mobile devices will do when specific objects are scanned, what will happen when they click specific buttons, how the devices announce that the game is over, who has won, etc. As users move through the game creation process, they are also able to test-run and debug the game with immediate feedback from the WLCP through the *run and debug* feature of the editor, which simulates game play, to help ensure game functionality. Students use and implement finite state machines and advanced language, vocabulary, and understanding that is typically reserved for undergraduate students in Computer Science. Students observe the results of testing their mobile devices in the context of their games and make adjustments accordingly. Once the games have been created in the WLCP, multiple users can log in as Game Players to play.

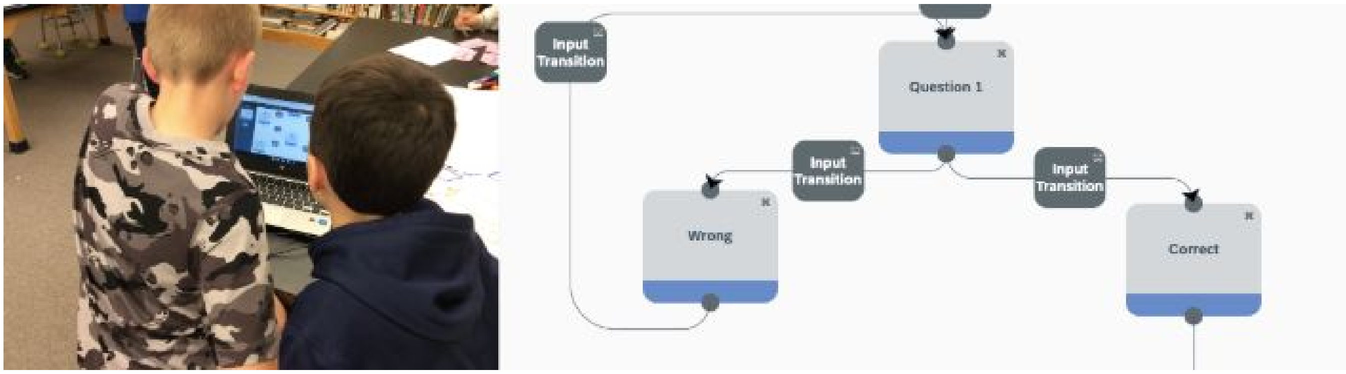


Figure 12. The WLCP platform is designed for students to program games through finite state machine structures with drag-and-drop game elements in the game editor.

Game Managers. The WLCP allows teachers and students to act as Game Managers to facilitate game play in addition to acting in the roles of Game Editor and Game Player. As Game Managers, users activate games on the WLCP for a specific group of users to play (Figure 13). This also allows multiple, simultaneous plays of the same game so that a teacher could allow 10 students or 30 students to play one game at the same time.

Figure 13. Left: A game manager selects a WLCP game for his or her students to play. *Right*: The game manager can view games that are in progress by his or her students.

While the WLCP has been used in prior work with students and teachers and we have seen positive effects of playing and creating games through the WLCP in lab-based settings and in classrooms (Arroyo et al., 2017), a majority of this previous work involved our team of researchers directly delivering instruction for the WLCP to students. Less emphasis has been placed on how to train teachers to effectively and feasibly integrate this platform into their own curriculum. To remove researchers from this process and keep teachers in the role of facilitators, the goal of the current project is to examine how feasible it is to train teachers to 1) create their own games, 2) effectively have their students play their developed games, and 3) have students create their own games through the WLCP in the classroom.

Chapter Seven: The Embodied Game Design Framework & The Professional Development Workshop

The Game Play and Design Framework

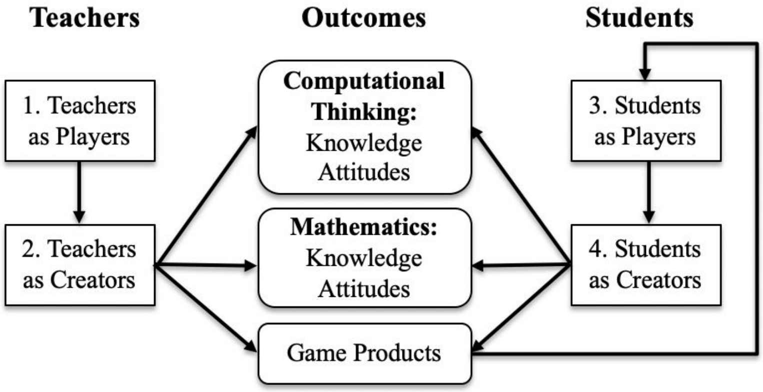


Figure 14. The Game Play and Design Framework, in four stages: Teachers as Players (Stage 1), Teachers as Creators (Stage 2); Students as Players (Stage 3); Students as Creators (Stage 4).

The Game Play and Design Framework is a series of game play and game creation experiences that allow teachers and students to integrate technology-based game play and game design in their own classrooms. The Framework is comprised of a 14-week curriculum that engages STEM teachers and students in higher level thinking and social learning through game play and iterative game design (Figure 14). To do so, the Framework consists of four stages that involve students and teachers as both game players and game creators. Students and teachers engage in tangible and social activities connected to mathematical content as game players and then become creators of educational games through a cyclical process. In turn, teachers and students reap the benefits of game play, such as collaborative learning and affective engagement with mathematical content, while at the same time obtaining the benefits of game creation, such as a deeper understanding of math content and problem-solving skills. Each of the four stages of the framework are described below.

Stage 1: Teachers as Players. Teachers are first introduced to the Wearable Learning Cloud Platform technology (described in the following section) by playing an existing active technology-based game. While the mathematical content of the game may be simple to teachers, the purpose of this activity is for them to have experience with the technology-based games as their students will do later in the process. As teachers engage with the technology and physically move through their environment, interacting with game props, they develop a context for understanding how the games are played and created, as well as a sense for how to incorporate math content in a way that utilizes mobile technologies and physical movement.

Stage 2: Teachers as Creators. Following the experience of playing a game that incorporates math, teachers are shown the finite state machine structure of the game as it has been programmed in the WLCP. Teachers then have the opportunity to create and design their own math game, in teams. They begin the creation process with a brainstorming session, followed by an interactive programming session that covers the basics of programming. Teachers then program their own games, gather and make any materials needed for gameplay, run and debug their games, and iteratively design their game until the games are ready for classroom use. During this process, it is expected that teachers will deepen their computational knowledge and develop more positive attitudes towards using games to develop computational and mathematical problem solving.

Stage 3: Students as Players. Once the teacher-created game is a functional product, teachers bring their games to their own classrooms. While teachers move into the role of game deployers and managers, students become game players within the context of the game that their teacher developed. As students play the technology-based game, they answer questions and solve problems related to class content by interacting with their peers, their environment, and the technology involved through active game play.

Stage 4: Students as Creators. After playing the games, students have the opportunity to become creators themselves as they design and program a math game of their own. Mirroring the process of Teachers as Creators, students begin by brainstorming game topics in small groups. Their teachers then introduce them to the programming platform and the students begin creating their games in a collaborative, iterative design process. Once the games are built, students run and debug the games before showcasing and playing their games with their classmates. During this process, it is expected that students will deepen their mathematical knowledge, improve positive attitudes towards CT and mathematical problem solving and creation.

Ultimately, the Game Play and Design Framework provides a novel approach for teachers and students to play and create instructional games augmented by mobile technologies to deepen student learning and promote computational and mathematical thinking skill development in STEM classrooms.

Through this project, we aim to answer the following research questions: RQ1) *Can middle school STEM educators successfully play, design, and create games in the WLCP?* RQ2) *Does classroom game play of teacher-developed games improve students' math learning?* RQ3) *Can middle school students successfully create games in the WLCP during classroom instruction?* In the next section, we discuss our methods to answer these questions.

Methodology

Participants

Twelve middle school STEM and math teachers completed the 14-week professional development program. Of the 12 teachers, nine were middle school math teachers (1 fifth grade, 2 sixth grade, 3 seventh grade, and 1 eighth grade), three were middle school STEM teachers (5-8th grade), and one was an after-school STEM activities coordinator. Together, roughly 400 students were exposed to the WLCP and Game Play and Design framework in their classes.

Procedure

In order to implement the Game Play and Design Framework in Figure 14, we developed a 14-week teacher professional development program to introduce STEM educators to the WLCP and explore the benefits of active game play and creation with their own students and curriculum, following the four stages of the framework. The program encompassed all aspects of The Game Play and Design Framework involving both the playing and designing of multi-player educational games for math. The timeline of the implementation is described in detail in Table 1.

During weeks 1-7 of the program (corresponding to stages 1 and 2 of the framework), teachers worked in groups of two or three. Each group contained at least one STEM teacher and one math teacher to encourage collaboration between teachers who may have different areas of expertise and classroom experience.

Stage 1 (Teachers as Players) was carried out during week 1 where participating teachers played an existing geometry game in the WLCP, created by graduate students, called the "Tangrams Race" (Figure 15). This experience provided them with a concrete experience of the possibilities of social interaction within the games, and the role that the cell phones could have within the educational game to support and guide players.

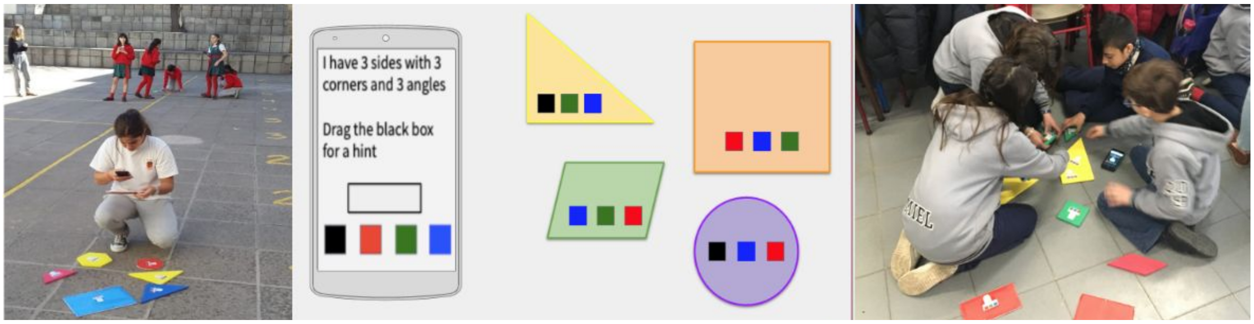


Figure 15. Students playing the "Tangrams Race", a relay-race geometry game that encourages students to associate mathematical descriptions to geometrical figures placed at the end line (left), which need to be brought back by each player to later construct a Tangram Puzzle (right). When the player decides one shape is a possible correct answer, they push/drag colors to complete the color sequence that identifies the shape (middle). The phone provides immediate feedback and offers help and support by dragging just black, until the student manages to succeed.

Stage 2 (Teachers as Creators) was carried out during weeks 2-7, where participating teachers first designed and then programmed original games in groups around their own curriculum and class-based needs. To start, teachers worked in teams to brainstorm potential math topics for the games**.** During week 3, teachers began designing their games on paper, and writing down rules of their games. During week 4, they were given a lesson about finite state machine diagrams (FSMDs), and were encouraged to make a sketch (on paper) of the concrete behavior of the cell phones as a FSMD. In week 4, teachers were also introduced to the WLCP editor and received a short programming lesson, which basically consisted of how to transfer their FSMDs from paper onto the WLCP web site. After learning how to use the WLCP, they were ready to program their games. During weeks 5-6, teachers programmed their games and were encouraged to use the run and debug function often to test their progress. The debugger would launch a simulator of a cell phone and show how the program would look when run on the mobile devices. During week 7, teachers demonstrated, explained, and played each others' games using cell phones and any other physical materials involved in the games.

During stages 3 and 4, (weeks 8-14), math and STEM teachers took different routes in their own classrooms. Math teachers finalized their games and had their students play the game they had created, in their own classes (note this corresponds to Stage 3, "Students as Players"). Teachers used cell phones, and any other physical materials that they had created to run the games in the WLCP software. STEM teachers also had their students play their finished games however, after their students played the game, they continued the cycle and helped their students begin the game design process (corresponding to stage 4, "Students as Creators"). Teachers also made their own set of instructions to teach their own classes how to program in the WLCP. By taking the time to learn how to use the WLCP, each teacher developed their own way to teach the game design process and programming to their students.

Table 1.

Game Play and DesignProfessional Development Program Plan and Timeline.

Stage/Weeks	**Description of Activity**
Stage 1: Teachers as Players (Week 1)	**Activity:** Teachers play an existing game in the WLCP, called the "Tangrams Race", followed by a discussion about the game content, and the role of the mobile technology to support players **Materials:** Geometric shapes with codes to play the "Tangrams Race"; a cell phone per teacher; observation sheet
Stage 2: Teachers as Creators (Weeks 2-7)	**Activity:** Teachers brainstorm game topics in groups of 2-3 people (Week 2) Teachers develop the game rules and design the game and finite state machine diagrams on paper (Week 3) **Materials:** Paper and markers
	Activity: Teachers learn how to use the WLCP and then work in groups to program their games (Weeks 4-6) **Materials:** Presentation introducing the WLCP and the wearablelearning.org website
	Activity: Teachers debug, revise, and play each others' games! (Week 7) **Materials:** computer; http://wearablelearning.org; mobile device; any materials needed to play their designed game
Stage 3: Students as Players (Week 8)	**Math Teachers:** Math teachers design assessments and have their students play their WLCP-created game in the classroom **Materials:** internet; mobile devices; any materials needed to play their game
Stage 4: Students as Creators (Weeks 9-14)	**STEM Teachers:** STEM teachers lead their students in the Game Creation process, mirroring weeks 1-7 above **Materials:** Students create games and follow weeks 1-7 above

Measures and Approach to Analyses

The general approach to the measures and approach to analysis varied depending on the stage of the process. We describe each below.

Stages 1 and 2: Teachers as Players and Creators. The most important feasibility metric was teachers' games; whether teachers produced full fledged working games to continue through stage 3. Additionally, we gathered two survey measures of Teachers' General Experiences and Usability after using the WLCP on week 7. The first survey consisted of ten 5-point Likert scale statements to be rated by teachers, regarding their experience using the WLCP, such as "*I needed to learn a lot of things before starting to use this system*", "*I felt very confident using this system*", etc. The items assessed several constructs from affective to cognitive comfort on using the WLCP and carrying out the activity in general. The second survey assessed the ease of use of the WLCP programming (game editor) tool on a 5-point Likert scale (5-*very easy* to 1-*very hard*). Teachers rated the usability of six programming aspects of game creation in the WLCP related to specific programming actions.

Stage 3: Students as Players. We were interested in analyzing the effectiveness of the teacher-created games in the classroom for teaching and learning math. Teachers designed and administered their own brief five- to six-question multiple-choice and short-answer pretests and mirrored posttests to students directly before and after playing the games in the classroom. Individually, the pre- and post-tests for each teacher allow us to analyze whether each game product was conducive to math learning, after student exposure to the mobile technology-based games.

Stage 4: Students as Creators. In week 14, students completed a usability survey similar to the teacher survey after their game creation process. Additionally, teachers kept journals of the students' game development process, including both positive aspects as well as difficulties faced in the classroom.

Chapter Eight: Results

Games Made by Teachers

The teachers produced a total of five games during the first 7 weeks of the professional development program. Three of the five teacher groups successfully completed and pilot-tested their novel games in their own classrooms. While the remaining groups successfully created mathgames using the WLCP, they were unable to implement the games in their own classrooms during the allotted 14-week period due to preparation for standardized testing and the ending school year. Below, we present three sample games that were developed by teachers in our professional development program. The three games cover material taught in 6th, 7th and 8th grade, each covering a different topic (integer addition and subtraction, percentages, and graphing equations).

What's My Line? *What's My Line?*, a slope-equation and graph-matching game, was designed by an 8th grade math teacher, Mrs. G and a 5th-8th grade STEM teacher, Mrs. F. The learning objective of the game is to review the slope-intercept form of equations to ensure that students can read and interpret equations. Working in small teams, students are challenged to match equations presented on a mobile device with the corresponding line on a paper graph at one of seven different stations around the classroom (Figure 16). The goal of the game is to move through all nine stations to correctly match each equation to one line on each graph before the other teams can finish the game.

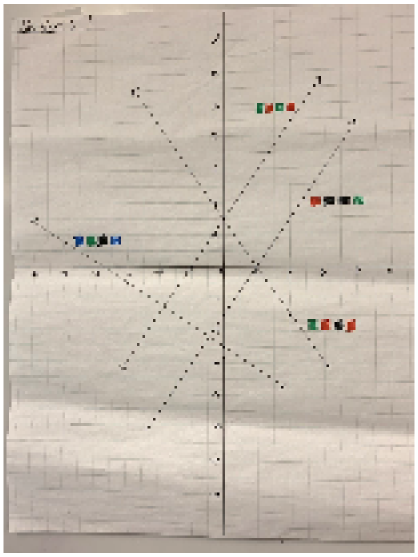
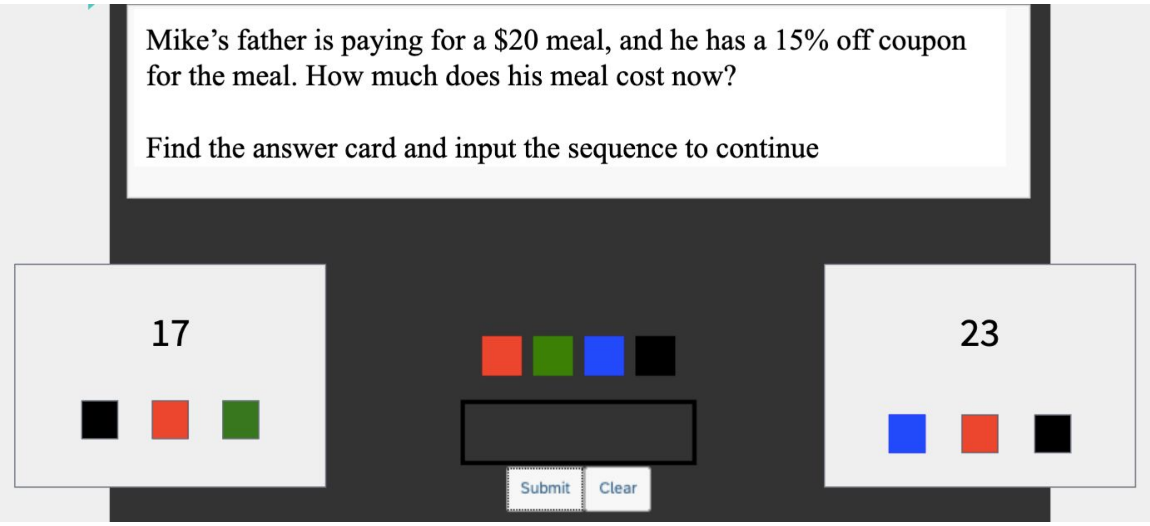


Figure 16. One of the seven graph stations featured in *What's My Line?* for small teams to choose the slope which matches an equation shown on their mobile device. Teams then drag-and-drop the correct color sequence (e.g. blue, green, black, blue) and receive immediate feedback on their phone.

Let's Shop. Another game, *Let's Shop* was designed by two 7th grade math teachers, Mrs. S and Mrs. B, and one 5th-8th grade STEM teacher, Mrs. M. The game features real-life scenarios where students are challenged with finding the correct price or discount of an item associated with a word problem. Example problems include calculating the tip at a restaurant, finding the sale price of a clothing item, or calculating the tax on a purchase (Figure 17). In groups, students work to figure out the answer and then locate the correct answer on a card somewhere in the classroom as if they are on a scavenger hunt. Players enter each answer into the WLCP on a cell phone. Correctness feedback on the submitted answer and hints to support problem-solving are provided to students. The goal of the game is to be the first team to complete all nine problems.



Mike's father is paying for a $20 meal, and he has a 15% off coupon for the meal. How much does his meal cost now?

Find the answer card and input the sequence to continue

Figure 17. An example screen display from the game, *Let's Shop*. Students are tasked with finding the correct answer on cards around the classroom (e.g. 17) and dragging the correct color sequence into the answer box for immediate feedback (e.g. black, red, green).

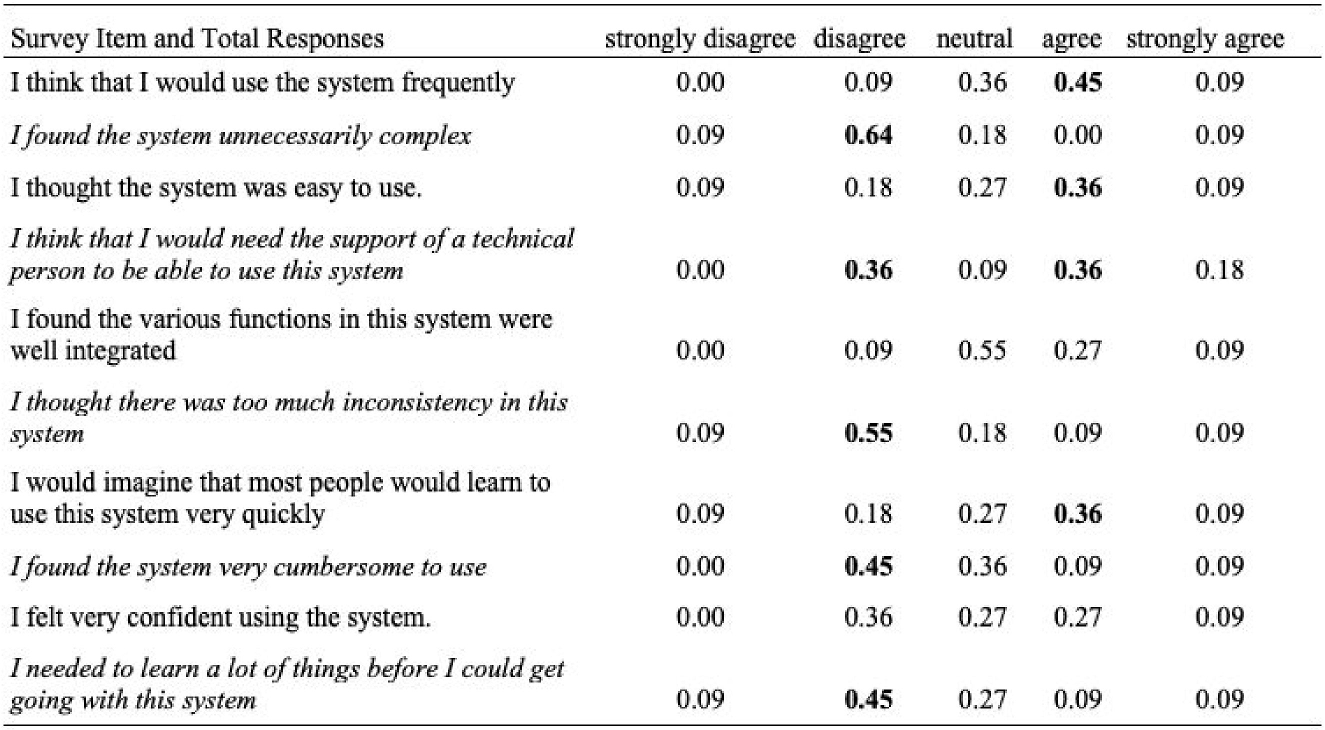
Integer Hopscotch. A third game, *Integer Hopscotch* was designed by a 6th grade math teacher, Mrs. T, a 7th grade math teacher, Mrs. L, and one 6th-8th grade STEM teacher, Mrs. D. The game gives students word problems that relate to addition and subtraction with positive and negative integers and has players walk along a 20-foot number line to find the answer to each problem. Students input each answer into the WLCP to receive immediate feedback and they always have the option to request a hint throughout the game. The goal of the game is to work in pairs to complete all of the integer addition and subtraction problems by moving along the number line.

Examining the Usability of the WLCP for Teachers

Eleven teachers filled out a survey about their experience using the WLCP during the Teachers as Creators part of the professional development program. Teachers rated how much they agreed with given statements about their experience on a 5-point Likert scale ranging from *strongly disagree* to *strongly agree*. The most common responses to each statement are reported below (Table 2).

Table 2.

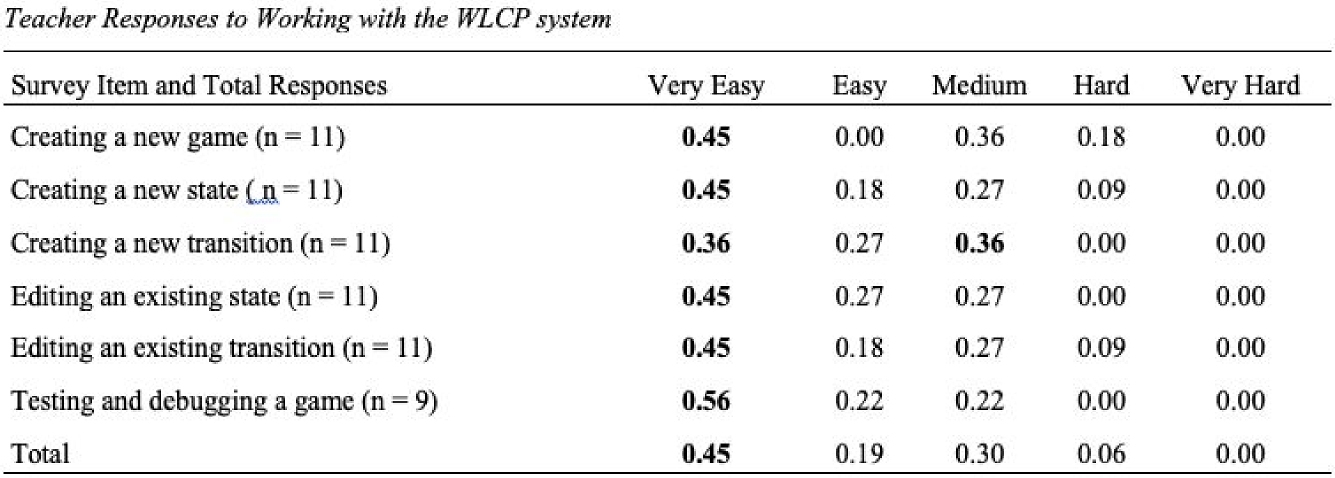
Teachers reported their overall impressions of the WLCP after designing their own games.



Survey Item and Total Responses	strongly disagree	disagree	neutral	agree	strongly agree
I think that I would use the system frequently	0.00	0.09	0.36	**0.45**	0.09
I found the system unnecessarily complex	0.09	**0.64**	0.18	0.00	0.09
I thought the system was easy to use.	0.09	0.18	0.27	**0.36**	0.09
I think that I would need the support of a technical person to be able to use this system	0.00	**0.36**	0.09	**0.36**	0.18
I found the various functions in this system were well integrated	0.00	0.09	0.55	0.27	0.09
I thought there was too much inconsistency in this system	0.09	**0.55**	0.18	0.09	0.09
I would imagine that most people would learn to use this system very quickly	0.09	0.18	0.27	**0.36**	0.09
I found the system very cumbersome to use	0.00	**0.45**	0.36	0.09	0.09
I felt very confident using the system.	0.00	0.36	0.27	0.27	0.09
I needed to learn a lot of things before I could get going with this system	0.09	**0.45**	0.27	0.09	0.09

Teachers also completed a survey to assess the usability of the WLCP on a 5-point Likert scale with item responses ranging from *very easy* to *very hard*. Teachers rated the usability of six programming aspects of game creation in the WLCP. The six items each correlate with programming actions within the game editing platform, as shown in Table 3. In general, teachers reported having positive experiences with the WLCP and reported positive outlooks on the usability of the WLCP in the future. Teachers also seemed generally confident in their ability to program using the WLCP (Table 3).

Table 3.
Teachers ranked the ease or difficulty of using specific programming features in the WLCP.



Teacher Responses to Working with the WLCP system

Survey Item and Total Responses	Very Easy	Easy	Medium	Hard	Very Hard
Creating a new game (n = 11)	**0.45**	0.00	0.36	0.18	0.00
Creating a new state (n = 11)	**0.45**	0.18	0.27	0.09	0.00
Creating a new transition (n = 11)	**0.36**	0.27	**0.36**	0.00	0.00
Editing an existing state (n = 11)	**0.45**	0.27	0.27	0.00	0.00
Editing an existing transition (n = 11)	**0.45**	0.18	0.27	0.09	0.00
Testing and debugging a game (n = 9)	**0.56**	0.22	0.22	0.00	0.00
Total	**0.45**	0.19	0.30	0.06	0.00

Stage 3 Results: Students as Players: Did Students Learn Math When Playing Teacher-Created Games?

To analyze the effectiveness of these games in the classroom, teachers designed and administered brief five- to six-question, mirrored, multiple choice pretest and posttests to students directly before and after playing the games in the classroom. We conducted repeated measures t-tests on the pretest and posttest scores of the students who played their teacher's game. Below we present results from three classrooms (Figure 18). Scores are reported in percentages.

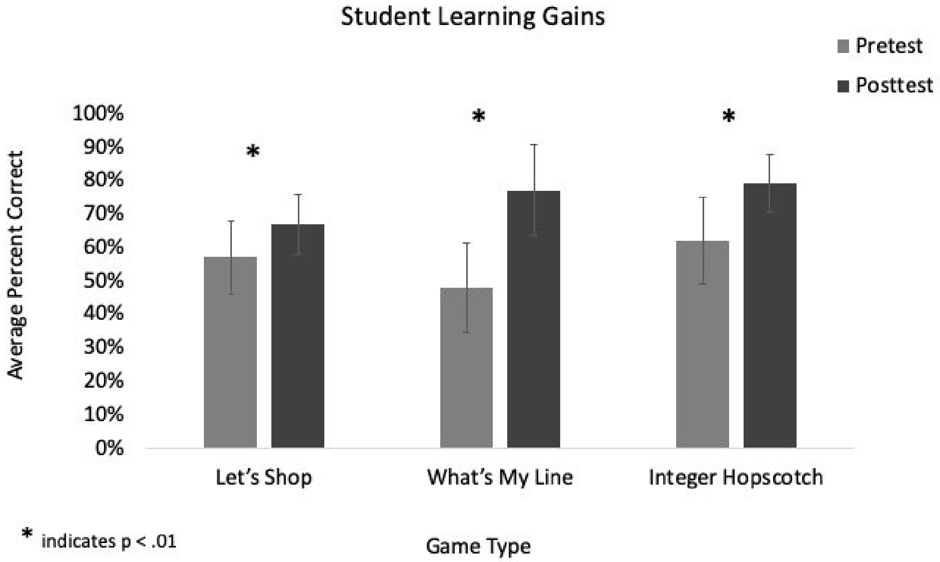


Figure 18. Playing the games designed by their teachers led to significant learning gains by students in brief pre- and posttest assessments.

What's My Line? Mrs. G tested the game, *What's My Line?*, with four of her 8th grade math classes (102 students total). Students began the class by taking a pretest to assess their knowledge of slope-equation and graph matching. This topic was focused on earlier in the year and Mrs. G noticed that her students continued to struggle with this content. To play the game, students were split into groups of 3-4 players with one cell phone per team. After completing the game, students took the posttest designed by Mrs. G and gave general feedback on their experience in a classroom discussion. A repeated measures t-test revealed that the 102 eighth grade students who played *What's My Line?* improved significantly from the brief pretest (M= .48, SD= .27) to posttest (M= .77, SD= .27), $t(101)$ = 7.15, $p < .001$.

Let's Shop. Mrs. S and Mrs. B tested the game, *Let's Shop!*, with eight of their 7th grade math classes (84 students total). However, only Mrs. S collected pretest and posttest data due to scheduling and time constraints. Mrs. S gave her students a pretest on percentages, an identified weak point for her students, at the beginning of class. Both teachers split their classes up into groups of 3-4 players, with one cell phone per group. After playing the game, Mrs. S administered her posttest to students. A repeated measures t-test showed that the 84 seventh grade students who played *Let's Shop* improved significantly from the brief pretest (M=.57 , SD=.22) to posttest (M=.67 , SD=.18), $t(83)$ = 3.12 , p = .002.

Integer Hopscotch. Mrs. T tested the game with two 6th grade classes (49 students total). She administered a brief pretest on students' knowledge of integer equations at the beginning of class before partnering students to play the number line game in pairs. Each pair of students was given a cell phone to play the game and took turns walking along the number line to find the answer from one problem to the next. After playing the game, the students took the posttest. A repeated measures t-test revealed that the 49 students who played *Integer Hopscotch* improved significantly from the brief pretest (M= .62, SD= .26) to posttest (M= .79 SD= .17), $t(48) = 6.39$, $p < .001$.

Stage 4 Results: Students as Creators

An Example Student-Created Game and Journaling about Students

Mrs. F, a STEM teacher, led her 5th grade class of 27 students through the Game Creation process, following the same curriculum that the teachers completed as participants in the professional development program. Mrs. F kept an informal journal reporting the process with updates and pictures as to how the students progressed over a four-week period during 50-minute class sessions. After playing an existing game, brainstorming in groups, and completing the paper diagrams depicting how they would program their games in the WLCP (Figure 19), students began programming on the WLCP platform in their groups. They then completed programming their game, gathered and created any materials necessary for gameplay (such as cards, balls, and other props), then tested and debugged their games in their groups. Ms. F reported that, "a few kids were naturals at programming" and that, "it's a nice process to see the kids working together. They are anxious to see their games played!" As a final step, the students were able to play each others' games in the class. Ms. F reported that, "they are so excited! Played one of the games today. Kids loved it!"

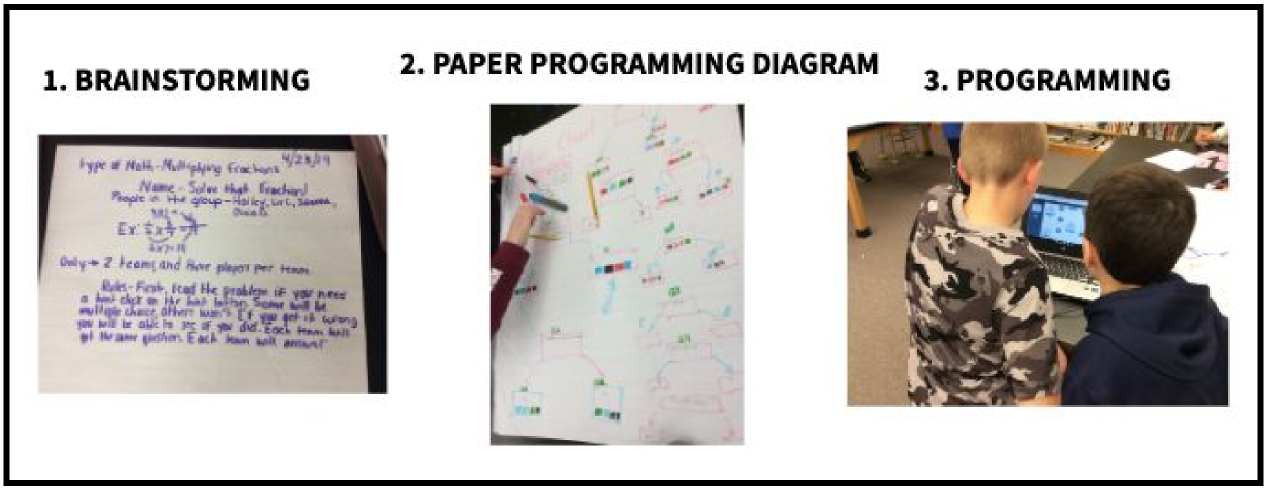


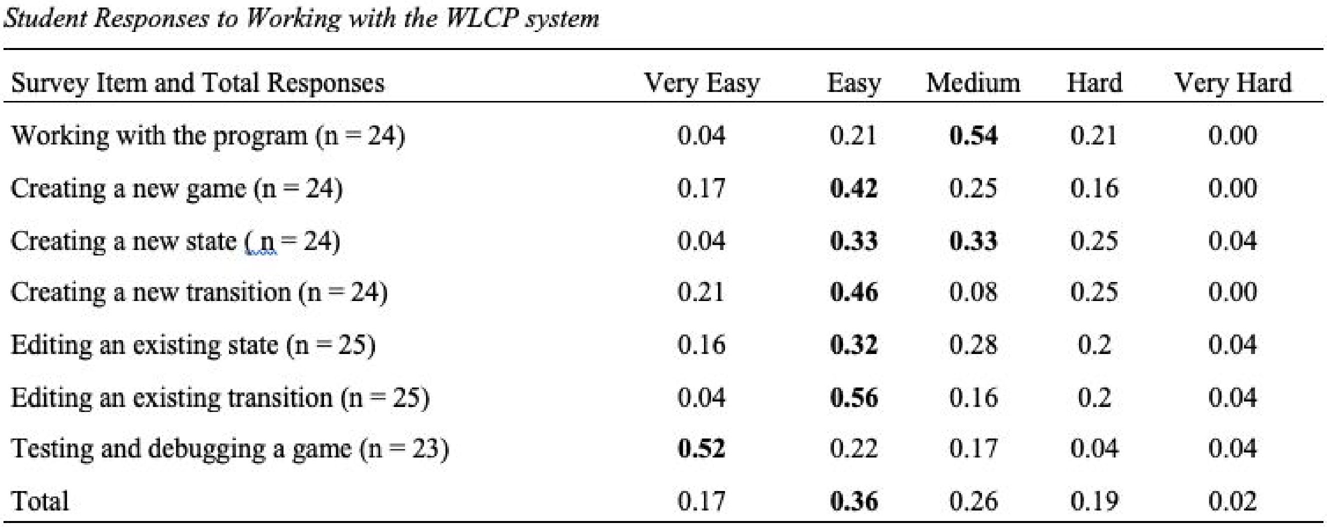
Figure 19. To fully engage in the game design process, students begin by brainstorming game ideas together in groups (left), then learn about finite state machines and practice designing their own (middle) before programming their game into the WLCP (right).

Usability of the WLCP for Students

Students who completed the Students as Creators portion of the Game Play Design Framework also completed the same survey as the teachers to assess general usability of the WLCP. Out of the 27 students that completed the game creation process, 25 completed the survey. The most common responses are displayed below (Table 4).

Table 4.

Students ranked the ease or difficulty of using specific programming features in the WLCP.



Student Responses to Working with the WLCP system

Survey Item and Total Responses	Very Easy	Easy	Medium	Hard	Very Hard
Working with the program (n = 24)	0.04	0.21	**0.54**	0.21	0.00
Creating a new game (n = 24)	0.17	**0.42**	0.25	0.16	0.00
Creating a new state (n = 24)	0.04	**0.33**	**0.33**	0.25	0.04
Creating a new transition (n = 24)	0.21	**0.46**	0.08	0.25	0.00
Editing an existing state (n = 25)	0.16	**0.32**	0.28	0.2	0.04
Editing an existing transition (n = 25)	0.04	**0.56**	0.16	0.2	0.04
Testing and debugging a game (n = 23)	**0.52**	0.22	0.17	0.04	0.04
Total	0.17	**0.36**	0.26	0.19	0.02

Chapter Nine: Discussion and Future Directions

The goal of the current project was to examine how feasible it is to train teachers to 1) create their own games, 2) effectively have their students play their developed games, and 3) have students create their own games through the WLCP in the classroom.

We implemented a 14 week professional development program to examine the feasibility of training teachers to use the WLCP in their classrooms and aimed to answer the following research questions. RQ1) *Can middle school STEM educators successfully play, design, and create games in the WLCP?* RQ2) *Does classroom game play of teacher-developed games improve students' math learning?* RQ3) *Can middle school students successfully create games in the WLCP during classroom instruction?* In the next section, we discuss our findings on each question and the overall outcomes of the program as well as future directions.

Outcomes of the Game Play and Design Professional Development Program

1. *Can middle school STEM educators successfully play, design, and create games in the WLCP?*

The first seven weeks of the program were largely successful. Through the professional development program, teachers were able to effectively complete the design process and produce playable math games for classroom use in the 7-week time period. Teachers seemed generally confident in their abilities to use the tool as creators and in their ability to program using it. Importantly, most teachers reported having positive experiences with the WLCP and reported positive outlooks on the usability of this web-based system in the future. Once teachers were ready to test their games in the classroom, they were also successful game managers, using the WLCP for their own students to play their games on cell phones in the classroom. Playing these games seemed to positively impact students' math knowledge, as evidenced by changes in pre/post assessments. Our results showed that teachers were able to effectively play, design and create games in the WLCP. These results have implications for using teacher-created games in the WLCP in the classroom as an additional learning activity for math students.

2. *Does classroom game play of teacher-developed games improve students' math learning?*

During the second half of the program, math teachers successfully ran the games in their classrooms. The games were shown to be effective learning activities as students made improvements from pre to post test after playing their teacher's games. Teacher developed games were successful in improving students' math learning. The results of the pre and post assessments add to the implication of using teacher-created games in the classroom.

3. *Can middle school students successfully create games in the WLCP during classroom instruction?*

The second half of the program (weeks 8-14) was also feasible for STEM teachers. They successfully implemented the game creation part of the program in their own classrooms. Teachers were able to effectively share and implement what they had learned through the professional development program with their students. As a result, students were able to produce games which they were able to test with their classmates. Students also reported confidence in their programming abilities within the WLCP.

Looking ahead, this program has prepared participating STEM and math teachers to implement the play-create process with their own students, using the WLCP web site, to cultivate a deeper understanding of math content through engaging activities. This ability for teachers to learn throughout the Game Play and Creation Professional Development Program and then teach the content suggests that the framework and the WLCP tool is feasible for classroom use in middle school math classrooms.

More broadly, we interpret these outcomes as evidence that the proposed framework and technology tool, the WLCP, are promising as STEM learning tools for use by middle school teachers and students. As players, students and teachers engage in collaborative learning to solve problems. As creators, students and teachers go beyond problem solving and display computational thinking by considering which games would be interesting to other students, thinking about how to blend mathematical material into challenges in the game, and then thoroughly planning the mechanics of the game, and specifying the behavior of the devices as a finite state machine. Ultimately, this work aims to introduce a STEM learning curriculum in which students and teachers play, design and create math games to encourage learning and engagement, and develop both teachers' and students' computational thinking and math skills.

Limitations

This work represents our first attempt at scaling up the Game Play and Design Framework using the WLCP. While we believe it was successful overall, we realized through the process that there were limitations, challenges, and areas that we would like to improve upon and explore in the future.

First, we did not collect any data on teachers and students' experiences during game play. Videotaped observations and surveys could be used to better understand and code teachers and students experiences and allow us insights into how the game playing experience could be improved. While each teacher did lead a classroom discussion on students' experiences after playing the games, a formal survey on students' experience would be more beneficial to assess and refine the game play portion of the Game Play and Design Framework. In the next iteration of this program, we intend to use measures of the game playing experience to explore student engagement and content learning gains to better understand the benefits of game play as opposed to game creation. A future goal is to compare the impact of game playing vs. game creation, or both, on math learning, as the latter most likely encourages deep thinking about math concepts through problem posing, and also makes students think about how to help or support future problem solvers (Arroyo & Woolf, 2003; Silver & Cai, 1996).

Next, we want to design better ways to assess student learning of mathematical content. Although three games were tested with class-wide use, not all of the created games were played to assess student learning gains. The professional development program was conducted in the spring, prior to, and during, state-mandated standardized testing. This timing introduced unforseen conflicts with teacher availability and reduced teachers' abilities to fully introduce game play and game creation in the classroom at the expense of test preparation. For instance, one teacher did not administer pretests and posttests to her students during the game playing portion of the program to minimize time away from content instruction. However, even with the pressure of state testing, teachers were excited and interested enough in the project to introduce this platform and their self-created games to their classes. Future versions of the program for educators will take place in the fall semester of the school year to mitigate scheduling and participation issues that arose from the upcoming standardized testing.

Additionally, this study did not include any pre or post measures of teachers or students Computational Thinking (CT), which limits us making any concrete conclusions on students and teachers development of CT skills. More broadly, the game creation process could benefit students above and beyond developing content knowledge by also exercising facets of CT (Wing, 2006). While CT was not directly measured during this program, the design process, including highly precise specification of games and the mobile technology behaviors in the game, exercises students' CT through decomposition, abstraction, and debugging. Prior work has shown that students who create games demonstrate facets of CT which are central to success in STEM fields, such as higher performance in problem solving, strategy use, system analysis and decision making skills (Akcaoglu & Koehler, 2014; Vos, Van der Meijden, & Denessen, 2011). Future implementations of the Game Play and Design Framework, through educator professional development programs and classroom studies, intend to encompass measures of CT to assess whether students develop such areas of higher-level thinking skills through the game creation component of the Game Play and Design Framework.

Implications for Teacher Education

The Wearable Learning Cloud Platform, the Game Play and Design Framework, and the professional development program can directly be used both by teachers and students to improve engagement and learning of STEM in the classroom, by providing the freedom to create and play educational games with a low-barrier entry for novice programmers. While this professional development program focused on math games, the WLCP can be used by educators and learners in other subjects to play and create curriculum-specific games to support teacher and student autonomy as well as student engagement and learning.

Future Work

Since, running the teacher professional development program we have improved upon and designed new research along the topic of implementation of the program and the WLCP in classrooms.

Game Playing. We plan to test the aspect of game playing and the effects of the three teacher-designed games presented in this thesis more. First, we plan to create uniform pre and post test measures based upon the common core standards covered in the games. We will use existing questions from state assessments and certified publically available textbooks. This will allow us to truly test the effectiveness of the games across classrooms, by having assessments that can be used by all who play the game and are not classroom specific. This will also strengthen our claims in that the tests will be more widely used. With the implementation of new pre and post assessments we also plan to test the games in other classrooms, rather than with the students of the teacher who designed the game.

We also plan to explore the physicality of the games. Games that are currently played in the WLCP often use the whole classroom and involve the students getting out of their seats and moving around the room to play the game. However, most games can also be played stationarily. We plan to explore the effects on learning between playing games in an active vs stationary form.

We also plan to develop a survey to assess students and teachers experiences *playing* the games in their classrooms.

Computational Thinking. One of the main limitations of this study is the absence of a formal pre and post test assessing computational thinking before and after creating games. We are currently developing a computational thinking pre and post assessment which will allow us to better understand the skills gained through creating games.

Feasibility. While we showed that teachers could successfully create and play games in their classrooms and students could successfully play games and follow their teachers instructions on game creation, the researchers still played a large role in the implementation of the program and of the framework. We are currently in the process of expanding our website to include game directions and materials so that teachers can play games in their classrooms without the direct assistance of a researcher. We are also developing tutorial videos on how to program in the WLCP so that anyone: teacher, student etc, can learn to create a game without a researcher being present. Teachers could also access tutorial videos and learn themselves and then teach their class of students. Teachers will also have the ability to create new games for their classroom's use.

We are also creating a downloadable guide to the professional development workshop and framework which can be followed by teachers themselves, or with their classes. It will explain how to go through each part of the framework, from player to creator, and will provide specific guidelines and materials to follow for each of the 14 weeks outlined in the program.

Conclusions

Overall, the results presented here support the feasibility and usability of the Game Play and Design Framework and provide examples of how the WLCP can be used by teachers and students in classrooms to promote learning, engagement, and problem-solving through game play and creation. The teachers' interest and fidelity to the program suggest that this is a promising professional development program and technology tool that may be feasible and worthwhile for STEM teachers to adopt in their classrooms as a way to integrate technology and concepts of CT into their existing STEM curricula.

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