# PRESCHOOLERS LEARNING SPATIAL REASONING SKILLS WITH DIGITAL AND NON-DIGITAL ACTIVITIES AT HOME: A PILOT STUDY

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## *ABSTRACT*

*This paper explores the development and initial testing of a home-based, preschool spatial learning program with digital games, books, and hands-on activities. Spatial thinking, despite its importance in future career trajectories, is not as commonly targeted as other mathematics topics and digital games and play-based activities hold promise in engaging preschoolers in fun, engaging spatial thinking learning. The pilot study involved 49 low-income preschool families to evaluate a home-based spatial reasoning intervention. Findings suggest that families were able to engage their children in mathematical activities successfully, parents began to see digital games as useful tools with unique affordances for learning, and most importantly, children made significant gains in spatial thinking after engaging in the program. The intervention's positive effects on preschoolers' spatial reasoning and caregiver engagement suggest broader societal benefits by supporting early math skills critical for future STEM achievement and educational success.*



## *KEYWORDS*

*Preschool, spatial learning, digital games, parental caregivers, tablets*


## 1. INTRODUCTION

This paper reports on the development of evidence-based, developmentally appropriate media, as well as associated research conducted to investigate how best to promote engagement in spatially focused mathematics learning activities for parental caregivers and preschoolers at home. This home-based intervention is intended to complement classroom learning and provides an example of how preschool educators can link playful home activities with overall learning goals for the classroom. Often these activities are shorter, simpler versions of what children experienced in the classroom, allowing children to practice spatial skills while parents continue to support the positive learning that research has demonstrated [1].

Spatial orientation, a sub-skill within the larger umbrella of spatial thinking, is often not the focus of educational experiences for young children [2], yet there is growing evidence that spatial thinking contributes to later mathematics achievement [3,4]. When thoughtfully designed, digital tools can serve as a vital gateway to support early mathematics learning and have demonstrated the ability to foster social interaction and collaborative learning [5]. An optimal environment for learning is created when caregivers and children effectively interact with digital resources

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designed for them and have access to guidance on how to use these tools to enhance children's understanding and engagement.

Excellent math education for young children is critical to foster quality instruction and support future academic success [6, 7, 8, 9, 10], as early mathematics learning is a strong predictor of future mathematics and reading achievement [9], particularly for young children at-risk of poor achievement [11]. Spatial abilities specifically have been found to be associated with achievement in STEM fields [12] and career choices [13]. Yet, spatial reasoning skills are not as commonly taught in early childhood as other mathematics topics [7]. Digital games may provide a way to engage young children in spatial reasoning, as digital technology has unique affordances that can build on theories of how children develop spatial reasoning skills through activities that are engaging and fun. While it is crucial that young children engage in relevant hands-on spatial activities (e.g., navigating real life spaces), digital games provide unique opportunities for children to repeatedly practice what they learn in the real world.

Yet throughout the development of these digital tools, attention must be paid to the key demands placed on the learner (cognitive, emotional, physical, and social). Digital games allow for the player (children playing alone or with an adult) to actively shape their own learning experience. Yet games for young children must be carefully crafted to meet their developmental needs. Players require sufficient challenge to stay motivated, both cognitively and emotionally through their connection to goals and characters; however, games created for young children must also consider specific developmental needs. For example, the mechanics of the game, in this case touch-screen technology, needs to be responsive to small fingers that may not be as accurate as older players (i.e. games must allow the child to succeed even without highly developed fine motor skills). Similarly, it is essential to create games that enable children to interact and socialize with both peers and adults through various means [14]. Our work extends the research on effective mathematics learning within the school context and seeks to address the existing gap in access to home-based learning resources with a spatial reasoning intervention for home use.

## 2. LITERATURE REVIEW

The concern about the mathematical performance of America's children [6,7, 8,10,15] has led to concerted efforts to improve mathematics education in upper elementary, middle school, and secondary school classrooms. A growing number of studies demonstrate that early mathematics learning significantly influences and forecasts future academic success [9,16], particularly for children who are at risk of underperforming in school [17]. The mathematics initiatives that do explicitly target preschool mathematics have traditionally focused on more basic skills, such as counting and shapes, rather than more sophisticated mathematic skills, such as spatial reasoning skills, that can help young children become robust mathematicians who are better prepare for the more sophisticated math they will learn in later grades. Engaging in STEM early also promotes positive attitudes toward STEM [18]. This may be particularly important for children at risk of lower school performance [7, 19]. Focusing on math-rich learning in the preschool years may provide an advantage to build their confidence and motivate young children's interest in STEM [20,21]. Research also suggests that children at this age voluntarily engage in math activities in playful ways that build foundational mathematics knowledge [20, 22].

The early years provide critical opportunities for leveraging children's intrinsic motivation to learn from math-rich interactions [22]. Young children spontaneously choose mathematical activities in their free play and see mathematics as highly connected to their lives [20] through activities such as comparing heights, building with blocks, and solving puzzles. Connecting these playful, spontaneous activities to core mathematical concepts can enable children to build the early mathematics knowledge and skills critical for later school success [20]. Yet, many children do not experience deep mathematical learning in either preschools or family environments, and children from low-income or underserved backgrounds tend to fall behind their middle-class peers on measures of early mathematical knowledge [19]. This has significant implications for future school success and engagement in STEM careers [23,24]. Fortunately, research shows that early, developmentally appropriate activities that engage children in rich mathematical learning—as provided in the intervention described here—can have a significant impact on mathematics knowledge when incorporated into school instruction [2, 3, 11, 25, 26] and by interaction with parents [27, 28, 29].

While school-based interventions show great promise for improving young children's mathematics learning, efforts that promote mathematics learning in other environments where young children spend much of their time—primarily their home—are also very much needed. Several research studies suggest that home interventions that foster structured, supported engagements between caregivers and children have also shown promise [24]. Research indicates that technology and media provide distinctive advantages for supporting learning at home [30], making it crucial to explore ways to harness these benefits, especially since families with young children now spend significant time using digital technology and media in the home environment [31, 32].

### 2.1. The Unique Importance of Spatial Reasoning

Spatial reasoning skills represent a unique approach, distinct from analytical, verbal, and logical-deductive approaches, to solving mathematical problems [33]. It is unsurprising that these skills are linked to success across STEM disciplines [34, 35] and are associated with mathematics performance starting as early as age three [36] and continuing through middle and high school [37]. In fact, differences in spatial abilities (controlling for verbal and math achievement) have been found to impact career choice [38], with more advanced spatial thinkers being more likely to major in STEM in college and to subsequently choose occupations within STEM [12]. These spatial reasoning skills can be cultivated, even at a very young age [7].

Unfortunately, there is currently a dearth of materials introducing spatial concepts at an early age [7], particularly materials that are designed specifically for parental caregivers and children to use together. To address this need, we developed digital and non-digital activities that support spatial reasoning in young children and piloted these activities with preschool children and their caregivers. The digital and non-digital activities were designed to complement and strengthen each other to support math talk and learning at home.

## 3. DEVELOPMENT OF THE INTERVENTION

The project engaged in iterative design and research phases to create a home-based spatial reasoning intervention that included both traditional, non-digital learning formats (i.e. books, hands-on activities) and digital tablet-based games designed to be developmentally appropriate and to promote spatial reasoning knowledge and vocabulary in unique ways. The digital games capitalized on the affordances of technology by providing multiple opportunities to explore, to practice, and to receive feedback during gameplay.

### 3.1. Intervention Co-Design Process

The research and development process started with the creation of a learning blueprint that outlined the targeted spatial reasoning concepts and vocabulary, informed by a review of relevant literature and established learning trajectories [7, 14]. The learning blueprint served as an "anchor" from which the intervention activities and child assessment items were developed. The blueprint included three overarching goals related to spatial orientation, navigation, and the use of models and diagrams. Subgoals are embedded within each overarching goal to make the learning goals clearer and explicit. For example, the spatial navigation learning goal (i.e. Describe, follow, and plan paths in real space using spatial vocabulary and relating one's position to key landmarks) was further described in a set of six subgoals (e.g. Children track their own directional movements within a space with respect to a single perceptually available landmark).

The resulting blueprint articulated learning goals and sub-goals that literature suggests preschoolers can engage with. The blueprint was then used to guide both the development of the learning activities and an individual child assessment used to evaluate the program; this ensured the learning activities and assessment items were based on the same set of learning goals but not aligned to each other as curriculum assessments are designed. Our avoidance of over-alignment between the learning activities and assessments was intended to ensure that the assessment would be a fair tool to evaluate the program's overall goals rather than the specific goals of each activity or the set of activities.

The co-design team consisted of researchers, curriculum developers, and media developers. The team used the blueprint to generate and further develop activity ideas and conducted formative testing of those activities with individual user testing to ensure that the activities were clear and engaging to preschoolers prior to the pilot study. Revisions to the activities were implemented based on formative research and a content review was conducted to ensure that the learning goals from the blueprint were addressed. Findings from the pilot study were then used to make a final round of revision to all activities prior to releasing them to the public via a webpage with the parent guide and games in the app store (links to be included after unblinding this paper).

## 3.2. Intervention Components

The intervention consisted of three digital games and sixteen non-digital activities (books, meal-time, paper-play time, and out-and-about time activities). The parent guide (Figure 1) provided families with a weekly schedule that indicated which of the digital and non-digital activities parents should focus on for each week and a description of each activity with suggestions for implementation. The schedule suggested activities for the week but allowed parents to select the time and day to complete activities based on their own daily schedule and also allowed families to complete multiple activities on one day, if desired.

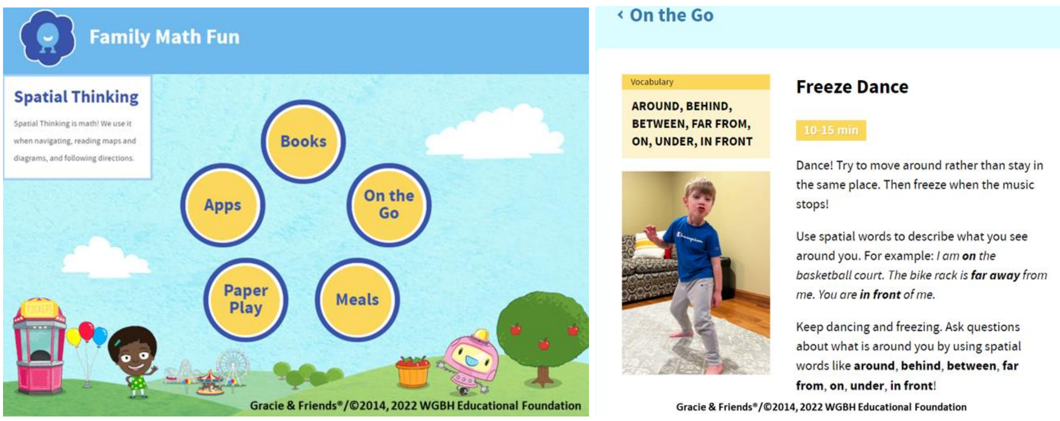



Figure 1. Parent Digital Guide and Example Activity Page

In the first two games, the players see a map of a farm or city (Figure 2) with pathways to each landmark. Players use their finger to drag their character to each location, and when they arrive at each location, they hear a song that describes the route that they took and see the character retrace the pathway taken. The third game allows the player to create maps by drawing roads with their fingers and, place various landmarks on the map. All games were designed to allow collaborative play with multiple players (i.e., more than one finger moving on the screen at the same time).


Figure 2. Map Adventure Game: City and Farm Maps

## 4. Methodological Design

The iterative development process included a formative user testing phase and culminated in a pilot study that serves as the first investigation into the potential of this intervention to influence preschooler's spatial reasoning skills and to determine the feasibility of this home-based approach.

### 4.1. Research Questions

The pilot study aimed to address the following research questions described in Table 1.

Table 1. Matrix of Research Questions, Data Sources, and Analytic Strategies

| Research Question | Data Sources | Analysis |
| --- | --- | --- |
| RQ 1. What evidence is there that the activities support progressively more sophisticated understanding of the mathematics related to the module content? | Child Assessment (Pre & Post)<br>Dyad Session Observation (Pre & Post) | Quantitative child assessment data and dyad scores underwent descriptive analysis and summary. A composite score for each of these data sources was generated and analysed using a paired-samples t-test to look for statistically significant within-subject changes over time. |
| RQ 2. To what extent are the digital prototypes and non-digital activities usable and comprehensible to preschool children and their parental caregivers? | Parental Caregiver Survey (Post)<br>Parental Caregiver Interview (Post) | Open-ended parental caregiver interview and survey responses were coded thematically to determine usability and comprehensibility of activities for caregivers and children, caregivers' perceptions of their children's learning, and the successes and challenges experienced. Quantitative responses underwent descriptive analysis, summary, and triangulation with qualitative themes. |

| Research Question | Data Sources | Analysis |
|---|---|---|
| RQ 3. Did the use of these materials impact parental caregivers' reported attitudes or behaviours about mathematics or technology learning in the home? | Parental Caregiver Survey (Pre & Post)<br>Parental Caregiver Interview (Post) | Open-ended parental caregiver interview and survey responses were coded thematically to determine the impact of the program on caregivers' attitudes and behaviours. Survey responses underwent descriptive analysis, and a composite score was generated and analysed using a paired-samples t-test to look for statistically significant within-subject changes over time. |

## 4.2. Participants

All children in these studies were three or four years of age and enrolled in Head Start preschool classrooms.

### 4.2.1. Formative Testing Participants

User testing was conducted through individual observations of each child's gameplay (n=34), and the mini-pilot was conducted with children during preschool after-school time (n=10).

### 4.2.2. Pilot Study Participants

The pilot was conducted in two preschools that serve low-income children for a total of 49 families. Two-thirds of the participating children were girls. The majority (82%) of participating children were of Hispanic or Latino ethnicity, and almost all of the participating children (94%) spoke English in the home. The highest level of education for parental caregivers varied, with some par-ents completing only high school (27% mothers; 41% fathers), attending either college or technical classes (31% mothers; 14% fathers), or completing a post-secondary degree (23% mothers; 6% fathers).

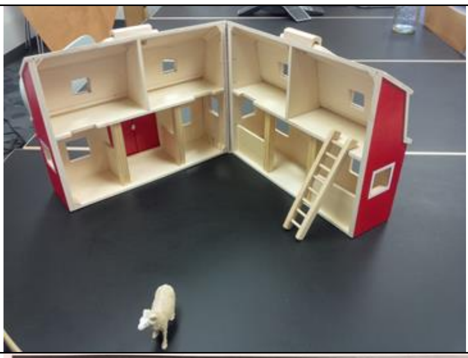
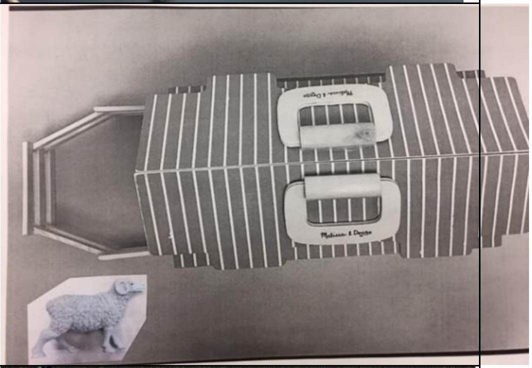
## 4.3. Research Instruments

The research team developed study instruments and used them for data collection.

### 4.3.1. Individual Child Assessment

Researchers on our team with experience in assessment development and Evidence Centered Design (ECD) [39] developed a child assessment to measure children's spatial reasoning skills, as no existing standardized assessment or subscale addresses the skills targeted in this project for this age group. Assessment items are intentionally aligned with learning goals that the research team articulated in the learning blueprint. Item formats were designed to adhere to developmentally appropriate methods for assessing preschool children's learning [40]. The team first designed developmentally appropriate, play-based item formats and then generated items that varied in terms of difficulty across learning goals. All participating children completed an individually administered pre- and post-assessment with a researcher that took approximately 25 minutes to complete. The assessment was subdivided into four main parts (see Table 2): (1) a toy barn and animals, (2) aerial tasks that show the barn from the top, (3) a 6x6 foot printed map with toy character driving a bus to various landmarks on the map, (4) an analogous paper-sized map that children navigated with their finger.

Table 2. Example Child Assessment Items

| Assessment Part | Example Learning Goal | Example Item Text | Example Item Picture |
|---|---|---|---|
| (1) Toy barn and animals | Find an object or location in real space (place learning) using vocabulary of spatial relations | Here is the sheep. Put the sheep on the ladder. |  |
| (2) aerial barn tasks | Children connect oblique (aerial) and eye-level views of a familiar space. | I am going to put this sheep here on this picture of the barn [assessor points to picture]. Put this sheep [assessor hands the toy sheep to the child] in the same place on this barn [assessor points to actual barn]. |  |
| (3) a 6x6 foot printed map | Children begin to use maps for navigation by locating starting and ending points, tracing possible routes between two points, and comparing alternative routes in terms of distance and efficiency. | (a) We are at the zoo. [Assessor places bus at the exit of the zoo]. Let's pretend we are meeting a friend for lunch at the pizza shop [Assessor points to the pizza shop]. Using the streets, drive the bus and show me how you would go to the pizza shop.<br>(b) Was that the shortest way to get to the pizza shop? |  |
| (4) Paper size map | Children begin to use maps for navigation by locating starting and ending points, tracing possible routes between two points, and comparing alternative routes in terms of distance and efficiency. | Now, let’s pretend you would like to stop at school first, before going to the cupcake shop. Using the streets, show me how you would walk to the school and then to the cupcake shop. You can use your finger to trace the path on this map. |  |

#### 4.3.2. Parent-Child Dyad Assessment

Participating parental caregivers completed pre- and post- dyad assessment activities with their children for the purpose of observing caregivers and children's interactions and use of spatial language. Prior to the activity, the dyad engaged in a five-minute, unscored orientation activity to familiarize participants comfortable with the format. The dyad engaged in three activities for up to five minutes per activity: (1) two hands-on mazes on a magnetic board, which was completed by moving a ball from a starting point to an ending point; (2) two paper mazes that were completed by using a crayon to draw the correct path from the starting point to the ending point; and (3) completing a set of activities in one of the intervention's digital games. For each set of activities, the child was given the opportunity to complete the activity first while the caregiver provided support and the second activity, the caregiver was given the activity to complete and the child was asked to help with verbal feedback or physical directions. The video recorded observation was later coded.

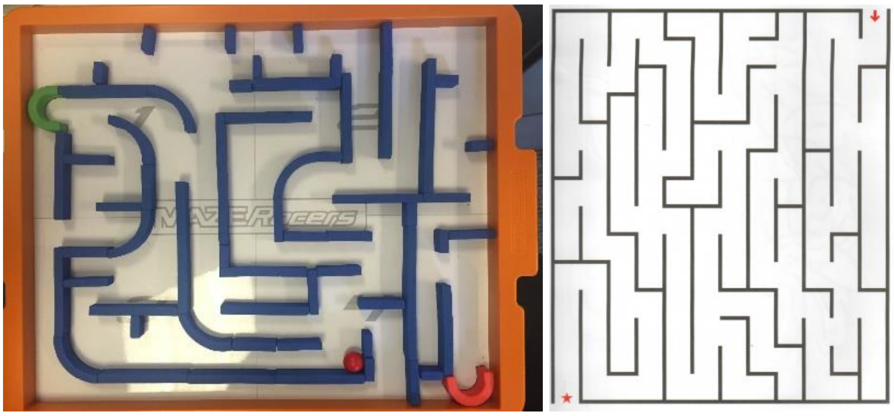


Figure 3. Example Dyad Maze Activity

#### 4.3.3. Post-Implementation Interview

Individual interviews with parental caregivers were completed after the post-dyad assessment session and took approximately 30 minutes to complete. Parents were asked to provide honest opinions about the use of the activities in order facilitate future changes to the activities. The interview questions inquired about implementation: how the activities were completed, whether the activities were completed solely by the child or jointly with a family member, and where and at what times the activities were primarily completed. Caregivers were asked for feedback on the activities themselves and suggested revisions. Interview questions probed for changes in children's behaviour or learning that caregivers noticed in response to the intervention activities.

#### 4.3.4. Parent Caregiver Pre- and Post-Surveys

Parental caregivers completed a pre- and post- intervention surveys. The pre-survey asked caregivers about their access to, and use of, technology in the home, the child's use of technology in the home, their beliefs about technology for learning, and their beliefs about math learning at home [41]. Additionally, the survey asked caregivers to describe any of the math-related activities typically completed at home. The post-survey asked caregivers to share information on their use of, and opinions about, the digital and non-digital activities, rate how well the parent guide prepared them to engage in activities with their child, and elicited suggestions for how the resources could be improved. Additionally, the survey asked caregivers if, after participating in the study, there was any change in their thinking related to math learning or spatial reasoning skills, or if they learned any new strategies for completing math activities in the home.

### 4.4. Procedures and Data Collection

The pilot study took place over 14 weeks with six weeks devoted to implementation of the intervention at home and four weeks before and after implementation for data collection. Child and dyad assessments were completed individually with a researcher, and surveys were completed during both data collection periods. Researchers conducted in-person caregiver orientation before or after school hours for approximately 20–25 minutes with small groups of caregivers. Caregivers received the tablet, all of the hands-on materials, a printed version of the guidebook, and a demonstration of all the activities. Once orientation was completed, families began their six-week implementation.

### 4.5. Analytic Approach

The goal of this pilot study was to evaluate the promise of the intervention and inform final revisions to the activities prior to their public release. Analyses were conducted in two ways to meet these complementary goals. First, researchers provided rapid feedback to the development team to inform design and guide revisions, which focused on families' experience (as reported by caregivers) with the activities. Subsequent analyses focused on answering the stated research questions using a mixed-methods approach. A composite score of the quantitative child assessment and dyad data was analysed using a paired-samples t-test to look for statistically significant within-subject changes over time. Qualitative responses to open-ended surveys and interview responses were analysed thematically to determine the usability and comprehensibility of activities for participants, caregivers' perception of their children's learning, and the successes and challenges they experienced [42].

## 5. RESULTS

The findings are organized by research question.

### 5.1. Research Question 1. What Evidence is there that the Activities Support Progressively More Sophisticated Understanding of the Mathematics Related to the Module Content?

To determine if preschoolers developed a more sophisticated understanding of the targeted mathematics and vocabulary, the child assessment and caregivers -child dyad data, along with parental caregiver reports of student learning were analysed.

#### 5.1.1. Child Assessments

Researchers computed descriptive statistics for each assessment item to better understand item performance, responses coded (correct, incorrect, partially correct), and a total composite score calculated. Findings from a paired samples t-test indicate that children made significant improvements from pre- to post-testing sessions, $t(34) = 4.98$, $p < .001$.

### 5.1.2. Parent Caregiver-Child Dyad

Researchers computed composite scores and conducted descriptive statistics for each dyad category coded and included activity completion, types of words (positional, proximity, spatial, directional), types of feedback (corrective, general, spatial, physical, and overall feedback), and navigational strategies. An overall composite scores included combined codes across all five dyad activities. There was not a significant difference in dyad activity completion from pre-testing (M=4.71, SD=.09) to post-testing (M=4.80, SD=.54); t(48)=.78, p > .47. This indicates that slightly more caregivers and preschoolers completed the activities after experiencing the intervention, but the difference was not statistically significant.

The types of words used was not statistically significant; however, three patterns in the composite means for caregivers and children suggest this should be investigated with a larger sample. Specifically, the use of positional words decreased for caregivers and increased for children, the use proximity and spatial words decreased for both groups, and the use of directional words increased for both groups.

Differences in three parental caregiver's assistance variables were statistically significant. Specifically, there was a significant decrease in frequency of assistance from pre-testing (M=3.80, SD=1.08) to post-testing (M=2.73, SD=1.43); t(48)=4.89, p > .000; verbal directions from pre-testing (M=4.20, SD=.84) to post-testing (M=3.12, SD=1.35); t(48)=5.80, p > .000; and physical directions from pre-testing (M=3.94, SD=1.05) to post-testing (M=2.29, SD=1.47); t(48)=8.00, p > .000.

Similarly, the use of navigation strategies decreased significantly for caregivers. Specifically, there was a significant decrease in parents' use of navigation strategies from pre-testing (M=13.88, SD=3.41) to post-testing (M=8.92, SD=4.10); t(48)=9.55, p > .000. Likewise, three types of caregiver feedback – corrective, general, and physical – decreased significantly over time. Specifically, there was a significant decrease in (1) parents' overall feedback from pre-testing (M=13.59, SD=2.84) to post-testing (M=9.22, SD=4.23); t(48)=8.15, p > .000, (2) parents' corrective feedback from pre-testing (M=3.96, SD=.93) to post-testing (M=2.57, SD=1.40); t(48)=7.03, p > .000, (3) parents' general feedback from pre-testing (M=3.98, SD=1.01) to post-testing (M=2.73, SD=1.32); t(48)=6.71, p > .000, and (4) parents' corrective feedback from pre-testing (M=3.82, SD=.95) to post-testing (M=2.33, SD=1.52); t(48)=7.44, p > .000. Overall, this suggests that caregivers did not need to provide as much feedback after the intervention as they did at the beginning.

### 5.1.3. Caregiver Survey and Interview

The majority of families reported that the digital games had a positive impact on children's learning (72% Game 1, 67% Game 2, and 60% Game 3). Caregivers responded affirmatively when asked if their child learned specific mathematics skills related to the unit with responses ranging from 65% to 98% (Table 3). Caregivers rating of overall impact of the intervention activities on their child's level of interest in learning new mathematics skills were high (62% a great impact, 36% some impact, and 2% no impact). Caregiver interviews indicated that they noticed a difference in children's spatial reasoning skills, use of spatial (i.e. right, left) and positional words (i.e. above, between, over, or under), and the majority affirmed changes in children's understanding of mathematics vocabulary words.

Table 3. Parental Caregivers Report of Children's Spatial Reasoning Skills

| | Yes | Unsure | No |
|---|---|---|---|
| Understanding an element-to-element correspondence between maps and the real world | 65% | 28% | 7% |
| Using a map for navigating to find objects or locations in real space | 78% | 15% | 7% |
| Understanding symbols or icons on maps as a representation of a landmark | 78% | 22% | 0% |
| Following directions or a series of landmarks to navigate a space | 79% | 17% | 4% |
| Understanding their own directional movements within a space | 85% | 15% | 0% |
| Understanding his/her location in relation to a landmark when moving within a space | 89% | 11% | 0% |
| Understanding positional words such "between", "above", "left", or "near" | 96% | 0% | 4% |
| Using positional words, like above, below, near, far (for example, "Can you put your toy under the table?") | 98% | 2% | 0% |

## 5.2. Research Question 2. To what Extent are the Digital Prototypes and Non-Digital Activities Usable and Comprehensible to Preschool Children and their Parental Caregivers?

Overall, the activities are usable and comprehensible to preschoolers and their caregivers. In interviews, caregivers reported that the activity length, number of activities, and paper guide worked well. Many caregivers reiterated the educational and entertaining aspects of the activities and that they helped preschoolers learn new words and concepts.

### 5.2.1. Implementation Patterns

Caregivers reported in interview responses that the majority of the activities were completed at home, while a small subset of participants engaged in hands-on activities outside by using directional vocabulary (i.e. left, right, ect.) while traveling or playing iSpy-type activities. Caregivers selected activities based on the amount of time available to complete the task. The majority of caregivers reported completing the majority of activities along with their child with a small number of activities completed alone or with a sibling.

### 5.2.2. Digital Activity Feedback

Caregivers reported minor technical issues with the digital games but also that the majority (94%) did not have any difficulties understanding the game's tasks. Caregivers appreciated the collaborative aspects of the games with built-in caregivers-child interactions. Caregivers liked that Game 1 provided playful interactions with animals. However, caregivers requested additional challenges for both digital games. Caregivers liked that Game 2 simulated parts of their real-world surroundings and contained landmarks their children saw in their neighbourhood (police station, school, library, ect.). Caregivers liked the collaborative, interactive, and creative aspect of Game 3 and that they were able to make real-world connections; however, caregivers also wanted more instructions and scaffolding in the activity.

Pilot findings led to a significant change in the final, released game in that the final game included elements of both Game 1 and 2 levels and additional levels that included moving obstacles that made navigation more challenging; Game 3 was not revised and the version that was released to the public was essentially the same as that used in the research study.

#### 5.2.3. Non-digital Activity Feedback

Caregiver reports suggest that the activities were usable and comprehensible with three main challenges reported: (1) finding the time to implement the activities, (2) one particularly challenging book that was too difficult for preschool children, and (3) that children were less engaged in the non-digital activities as compared to the digital games.

### 5.3. Research Question 3. Did Use of these Materials Impact Parental Caregivers' Reported Attitudes or Behaviors About Mathematics or Technology Learning in the Home?

Overall, caregivers reported that the materials were useful and usable. The majority (71%) of caregivers surveyed did not require more information or resources and reportedly benefited from using the guide (63%), attending the in-person orientation (58%), and trying activities themselves (58%). Caregivers also rated each digital game (98-100%) and hands-on activity sets (93-96%).

#### 5.3.1. Parental Caregivers Learning and Comfort with Mathematics and Technology

In response to questions asking whether strategies for introducing new spatial reasoning skills and concepts were similar to, or different from, how they normally do activities, caregivers reported both similarities (56%) and differences (44%) from normal activities conducted at home. Caregivers (89%) also reported that the intervention changed the way they interact with their child when introducing new mathematics. Caregivers reported in interviews that there were changes in their own thinking about mathematics, vocabulary, or spatial reasoning skills and 69% of caregivers reported that they had learned new strategies for teaching their child mathematics and spatial concepts.

On the post- survey, caregivers were asked multiple questions regarding their intended future use of the materials, as well as their intentions for continuing to use strategies to support their child's math learning and spatial reasoning skills. The large majority of families indicated that they would use the materials again in the future (92%). Caregivers were also asked to identify how often, if at all, they would continue to do specific math activities with their child at home (Table 4). More than half of the caregivers indicated that they would continue to engage their child in all of the activities on a daily basis, with the most common activity being encouraging their child to ask questions about new math concepts. Furthermore, when asked how much of an overall impact the use of the materials will have on the caregivers' comfort with introducing new math skills and concepts, 72% of all participating families said that it will have a great impact, 26% some impact, and 2% reported no impact.

Table 4. Parental Caregivers Future Engagement in Mathematics Activities

| | Daily | Weekly | Monthly |
|---|---|---|---|
| Play hands-on activities that introduce new math concepts | 51% | 49% | 0% |
| Play digital apps and games that introduce new math concepts | 53% | 43% | 4% |
| Encouraging your child to draw or label the location of an object in a picture or on a map | 57% | 34% | 9% |
| Use new math concepts while doing puzzles and board/card games | 60% | 36% | 4% |
| Play a game with my child while outside, such as naming landmarks on the street | 67% | 24% | 9% |

| | Daily | Weekly | Monthly |
|---|---|---|---|
| Help my child explore and talk about new math concepts using books, games, puzzles, or other toys | 70% | 23% | 6% |
| Ask my child to explain the location of an object in a real space | 71% | 22% | 7% |
| Help my child explore and talk about new math concepts | 74% | 21% | 4% |
| Encourage my child to ask questions about new math concepts | 79% | 19% | 2% |

## 6. LIMITATIONS AND FUTURE RESEARCH

The project laid out clear learning goals, developed materials and activities based on those learning goals, iteratively tested the activities before revising them, and conducted a pilot study to determine the initial promise of this approach. These goals were met; however, there are clear limitations to our findings. Because this iterative approach culminated in a pilot study and that pilot study informed the final set of revisions to the activities (including the digital activities), the publicly available activities have not been tested in their final form. In addition, we did not compare the outcomes to a comparison group of children who did not experience the intervention; thus, it remains a possibility that preschool children would learn the assessed content in the absence of the intervention due to maturation or other educational experiences. In addition, our individual child assessment holds promise but has not been vetted by the typical battery of measurement studies that standardized assessments have undergone. Future work on both the value of the intervention and the assessment is warranted.

More broadly, these findings suggest that the intervention's digital games address key areas of school readiness: cognitive, emotional, physical, and social skills. However, we did not measure learning in all of these areas, thus future research should attempt to ascertain a fuller array of outcomes.

## 7. DISCUSSION AND CONCLUSIONS

Prior research suggests that young children in preschool settings and at home benefit from structured, play-based mathematics activities. This paper explored the development and initial testing of a spatial reasoning program for preschoolers to engage at home with their parental caregivers; the program included digital games, books, and hands-on activities. Spatial reasoning was chosen due to its importance in future mathematics learning as well as its importance in STEM achievement and interest more generally. Findings suggest that families were able to successfully engage their children in spatial reasoning activities, caregivers came to see digital games as useful tools with unique affordances for learning, and most importantly, children made significant gains in spatial reasoning after engaging in the program. That is, the integration of digital activities improves preschoolers' mathematics learning has some preliminary supporting evidence to warrant further investigation into this approach.

The dyad assessment findings suggest that caregivers provided less support as preschoolers completed spatial task in conjunction with a small increase in the number of activities successfully completed, although the successful completion was already high at the beginning of the study due to caregivers' support (i.e. ceiling effect is likely). This suggests that the children were better able to complete these tasks with less support after experiencing the intervention—a beneficial outcome. In addition, caregivers reported that the activities were engaging and appropriate for home use and many families plan to continue using these activities in the future.

To scale this program up, future efforts should focus on expanding access through partnerships with early childhood education centers and community organizations, integrating the intervention into existing preschool curricula, and leveraging digital platforms to reach a broader and more diverse population of families while providing ongoing support and training for caregivers to sustain engagement and maximize learning outcomes.

Overall, the findings suggest that a home-based intervention with learning activities that are carefully developed to align with developmentally appropriate learning goals have potential to positively affected preschoolers' spatial reasoning skills and their caregivers' comfort with engaging in mathematical learning activities with their child. The findings also suggest that the implementation model – a short intervention with a mix of developmentally appropriate digital and non-digital learning activities that are provided to parental caregivers along with a short guide- was feasible and enjoyable to implement within the home context. Future research should focus on establishing the psychometric properties of the child assessment, investigating the optimal integration of digital activities with traditional, hands-on activities to support young children's mathematics learning, and conducting research with a comparison group to determine the extent to which spatial reasoning improvements are due to the intervention.

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