Next Generation Preschool Math Demo: Tablet Games for Preschool Classrooms

Christine Zanchi
WGBH Educational Foundation
One Guest Street
Boston, MA 02135
+1 (617) 300-4015
christine_zanchi@wgbh.org

Ashley Lewis Presser
EDC
96 Morton Street, 7th Floor
New York, NY 10014
+1 (212) 807-4264
alewis@edc.org

Phil Vahey
SRI International
333 Ravenswood Ave
Menlo Park, CA
+1 (650) 859-2143
philip.vahey@sri.com

ABSTRACT

This paper describes the Next Generation Preschool Math project, a $3 million, four-year research and development initiative funded by the National Science Foundation. Over the past year and a half we have developed and tested more than 50 interactive prototypes to teach preschool math learning. We will discuss the eight apps that emerged from that work, as well as the prototypes. We will detail the iterative and collaborative production process that included researchers, developers, and teachers.

Categories and Subject Descriptors

D.2.1 [**Software Engineering**]: Requirements/Specifications – *elicitation methods.* D.2.2 [**Software Engineering**]: Design Tools and Techniques – *user interfaces.* H.5.2 [**Information Interfaces and Presentation**]: User Interfaces – *input devices and strategies (touchscreen) – interaction styles (direct manipulation) – prototyping – screen design – user-centered design.* H.5.3 [**Information Interfaces and Presentation**]: Group and Organization Interfaces – *computer-supported cooperative work – evaluation/methodology.* K.3.1 [**Computer Uses in Education**]: Collaborative Learning.

General Terms

Design, Experimentation, Human Factors

Keywords

Early childhood, Preschool, Mathematics, Technology, Tablets, Collaborative learning, Production process, Co-design, Social learning

1. INTRODUCTION

The Next Generation Preschool Math (NGPM) project is a collaboration between researchers and media developers to develop a two-unit preschool math curriculum supplement that supports young children's learning of subitizing and equipartitioning [1, 2]. Each unit combines digital games, for both individual and collaborative play, and non-digital activities to support student learning.

Most preschool teachers are unprepared to teach mathematics and thus provide few rich mathematics learning opportunities for young children. NGPM is creating and evaluating a set of digital and non-digital resources to promote early mathematics learning. To create materials that are engaging, are age appropriate, and support young children in learning rich mathematics, we integrate research on (1) early mathematics learning trajectories, (2) developmentally appropriate joint media engagement, (3) preschool teacher professional development, and (4) evidence-centered assessment design. The integration of these approaches requires an extremely diverse team.

To meet this challenge we created an interdisciplinary process based on the design-based research literature, which allows for the integration of perspectives through the use of a blueprint "boundary object" that could be used across the different areas of expertise.

The research team generated such a boundary object—a learning blueprint that includes the learning goals, example tasks, and an expected trajectory through the goals. In parallel, the game design team iterated on the overarching context and game ideas. The complete multi-disciplinary team then engaged in a process of iterative refinement that included storyboarding, prototyping, and rounds of user testing with preschool children and teachers. Simultaneously, we developed an assessment, also based on the blueprint, to evaluate children's learning of the target mathematics.

2. CONTENT OVERVIEW

The project addresses the need for instructional materials that support the development of early rational number reasoning, a key goal of mathematics education reform [3]. The need for preschools to employ a challenging, research-based curriculum in early mathematics has been supported by numerous organizations [4, 5]. In addition, current research on the effectiveness of these curricula on early mathematics learning is promising [6].

Our NGPM materials focus on two mathematics topics, *subitizing* and *equipartitioning*, which receive little attention in the preschool years, even in most research-based curricula. Subitizing, or the ability to quickly determine the number of objects in a group without counting, was selected for unit 1 in order to support young children's growing understanding of number and quantity [1]. Equipartitioning, or the ability to create equal-sized groups of objects or equal-sized parts of one object, was selected for unit 2, as equipartitioning is foundational for

Interaction Design and Children '13, June 24–27, 2013, New York, New York, United States.
ACM 978-1-4503-1918-8.

more sophisticated rational number reasoning concepts, such as ratio and proportion [2].

2.1 NGPM Asset System

We designed our materials to integrate with existing structures and routines in preschool classrooms (i.e., whole-class circle time, small-group center-based play, and individual or paired computer time). Much of the learning students do in a preschool classroom is social, and working with technology is no exception. Social processes such as imitation, observation, and joint attention are fundamental to human learning from an early age [3]. Thus, we created games for individual and collaborative play so that children can build skills individually and collaborate with peers and teachers. Each unit combines digital games, including individual and collaborative games, and non-digital activities to support student learning.

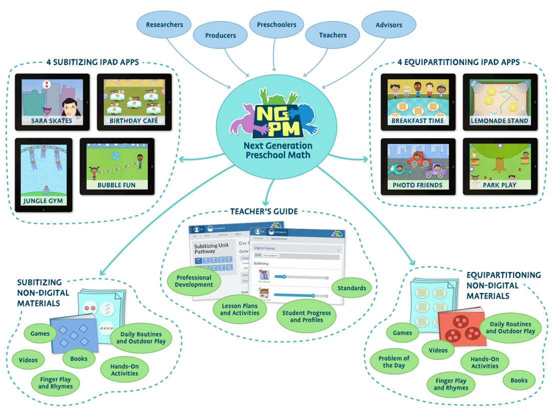

Figure 1. NGPM asset system

2.1.1 Digital Assets

Our final set of digital assets consists of eight tablet apps. For subitizing, the apps are *Sara Skates*, *Birthday Café*, *Jungle Gym*, and *Bubble Fun*. For equipartioning, the apps are *Breakfast Time*, *Lemonade Stand*, *Photo Friends*, and *Park Play*.

2.1.1.1 Non-digital Assets

Our set of 101 non-digital assets include songs, finger plays and rhymes, books, hands-on games, snack-time activities, and outdoor play. The hands-on games were developed to have a close correspondence with the digital assets.

2.1.1.2 Teachers Guide

The interactive teachers guide features professional development modules and videos, lesson plans, and activities as well as a real-time student progress monitor.

3. GAMES PRODUCTION PROCESS

We developed our games to align with three play modes: (1) individual, self-leveling play, (2) collaborative play between peer-peer or adult-child, and (3) sandbox play, which offers non-linear, open-ended learning.

3.1 Self-Leveling Games

Four of the eight games are designed as linear, individual experiences where a single player progresses according to his or her input. Correct answers move players forward along the math learning trajectory; incorrect answers prompt increasingly detailed feedback and intervention in order to support conceptual understanding. We also provide data on children's game progress to teachers, and part of our teacher professional development includes guidelines for teachers working with children who are struggling in the game.

3.1.1 Sara Skates

In the subitizing game *Sara Skates*, children must help Sara collect groups of two, three, four, or five objects as she skateboards through her city. Sara is constantly moving onscreen (using a side-scroller game mechanic) while groups of party supplies appear onscreen for approximately two seconds. By tapping on the iPad screen, children make Sara jump to collect the groups of party supplies that contain the target quantity. If the child collects too many incorrect groups, he or she has to start that level over again. The game levels up by increasing the quantity of supplies in each group (from two to five), by increasing the arrangements and complexity of the objects themselves within the groups, and by placing more groups onscreen at the same time. Built-in scaffolding allows children to learn the game mechanic, to see various arrangements and examples of the groups to be subitized, and to provide visual examples if children make too many mistakes. An intervention is triggered if a child consistently does not make gains in subitizing proficiency.

During the design process, we wrestled with the challenge of discerning when a child was having trouble with the game mechanic versus struggling with the math content. To mediate difficulties we then created a "training round," which takes players through each of the essential user interface features, such as tapping to jump and double-tapping to double-jump. We found that this significantly increased students' proficiency with the game mechanic and allowed them to focus on the subitizing task during play.

3.1.2 Birthday Café

In the subitizing game *Birthday Café*, children must seat the correct number of friends at each table and then deliver food trays to the tables so that everyone gets something to eat. In the first task, seating friends at a table, children match the number of friends in a group to a table with the same number of chairs. The numeral is also displayed on the table until the friends are seated. Children then drag trays of food from a moving conveyor belt to the tables so that the number of food items is equal to the number of children at the table. The food moves along the screen quickly, which allows children to subitize before placing the trays. If a child continues to not place the trays appropriately, the trays move more slowly, allowing the child the scaffold of counting the number of food items. If a child still does not exhibit proficiency in the game, an intervention is triggered to provide an untimed review and scaffolding to understand the target quantity.

We originally explored *Birthday Café* as a collaborative game, where two students worked together to seat and feed guests. While this design worked well for simultaneous screen play, each child often remained focused on his or her own task. There was less math talk and interaction than we had hoped for in a collaborative game, but since the activity was so engaging, we kept it as a self-leveling game.

3.1.3 Breakfast Time

In the equipartitioning game *Breakfast Time*, children must share breakfast foods equally among friends. The game targets equipartitioning both collections and continuous wholes (solid shapes or objects). Children drag their fingers across the iPad screen to divide waffles and watermelon slices into equal serving sizes for their friends. Children also fill bowls with yogurt and equipartition collections of berries into the bowls. If the food has not been correctly equipartitioned, the child's attention is drawn to the plates or bowls that have more than their fair share of food, and the child is able to reset the level and try again. If the food has been correctly equipartitioned, the child distributes the equal shares of food to the friends and moves on to the next level.

A key design challenge in *Breakfast Time* was determining the mechanic for children to precisely equipartition wholes (rather than make imprecise cuts in the food and never actually have equal partitions) when intending to. To this end, we offered "possible cuts" by displaying notches in the sides of the waffles and watermelon rounds so that children knew where the foods could be sliced. This also provided scaffolding for children because if all possible cuts were made, the equipartitioning task could turn from equipartitioning wholes to equipartitioning collections, a developmentally easier task.

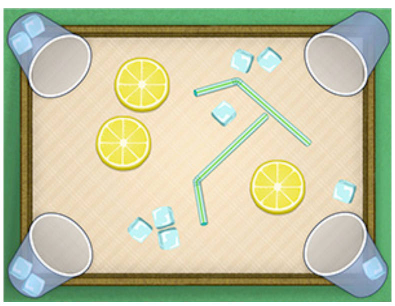

Figure 2. *Lemonade Stand* tablet game

3.1.4 Lemonade Stand

In the equipartitioning game *Lemonade Stand*, children equipartition a collection of ice cubes into cups. In each level, customers come to the game's lemonade stand and request a certain number of cups of lemonade. Children tilt the iPad to slide ice cubes into cups so that each cup gets the same amount. If a child has allowed too many ice cubes to slide into a cup, the child can drag an ice cube out of the cup and redistribute it into another cup. If a child has incorrectly equipartitioned the ice cubes and presses the Done button, the child's attention is drawn to the cup that has more than its fair share of ice cubes. If a child has correctly equiparititioned the ice cubes, the child pours lemonade from a pitcher (by tilting the iPad) to fill the cups. Children then tap on customers to watch them drink the lemonade. The game levels up by increasing the number of cups and the number of ice cubes. Advanced levels include obstacles, holes in the sides of the table through which ice cubes can fall, and ladybugs that must be kept out of the cups.

In *Lemonade Stand*, we took on the challenge of using the accelerometer as the key game mechanic. After several tests, we decided to add direct manipulation to enable players to drag and drop ice cubes from the cups onto the table in order to support a key equiparitioning strategy, redistribution (which also becomes essential in higher levels).

3.2 Collaborative Games

Collaborative game design is a challenging and exciting opportunity to immerse children in a shared learning experience. There are many modes of collaboration, ranging from observation to turn-taking to participation in a common task. Our goal was to design math tasks that children needed to complete together in order to succeed in the game.

Figure 3. *Bubble Fun* tablet game

3.2.1 Bubble Fun

In the subitizing game *Bubble Fun*, children work together in pairs to pop bubbles containing a particular number of objects. The game introduces groups of objects at the beginning of each round by having children tap and hold characters to blow bubbles containing the groups. Once all the bubbles have been blown, the bubble popping starts. Each child holds one end of a rope by pressing a finger against one of the characters. The target number appears onscreen inside a bubble. Together, the children must move the characters around the iPad screen and use the rope to pop bubbles as they fall—but only the bubbles containing the target number of objects will pop. When the child attempts to pop incorrect bubbles, those objects flicker and the child is reminded with an audio cue to look for the correct number.

The holding mechanic to slowly blow the bubbles came from a prototype field test where this mechanic was found to provide a rare learning opportunity by facilitating a slower, more deliberate pace. Teachers appreciated the think time this mechanic supports. In *Bubble Fun*, the mechanic allows children to become familiar with the groups subitized in the second part of the game.

The second part of the game requires players to "hold" the rope and work together to pop the correct bubbles by "catching" them. Characters hold the end of the rope to indicate where each player should tap and hold. We extensively iterated this mechanic, from restricting the areas on the screen where players could move their finger, to how to introduce the idea that each player had to take up a side of the rope. We ended up allowing a full range of motion—a simple up-and-down motion felt broken, and it limited the fun of the game.

3.2.2 Photo Friends

In the equipartitioning game *Photo Friends*, children work together to distribute items to characters in different scenes. The game begins with children taking pictures of each other using the iPad. Children then choose a scene in which their photos appear (wearing a bunny, bee, or flower costume). In each scene, items must be correctly equipartitioned among the costumed characters. When the objects have been correctly equipartitioned, the scene animates. For example, in the scene in which the children's photos are shown in bunny costumes, the children must divide a number of carrots equally among the bunnies. When this is done correctly, the bunnies jump up and down. If objects are incorrectly equipartitioned, children can redistribute the objects by dragging them from one character to another.

We anticipated that the challenge for this collaborative game would be how to help children use the camera, but this proved not to be a challenge after all. Instead, the main challenge for *Photo Friends* was determining how both children could engage in the same equipartitioning task without simply “filling slots.” Allowing for incorrect answers and redistribution made children have to pause, think, and discuss the problem to get the right answer.

3.3 Sandbox Games

Sandbox games allow players to explore concepts in a non-linear fashion, usually without a reward system or direct instruction. This proved to be a particular challenge, as our design imperative was to teach math, and our target audience, while they enjoy open-ended experiences, were quicker to leave a game that did not offer a linear path and engaging feedback. Thus, our NGPM sandbox games are scaffolded to provide more direct learning experiences.

3.3.1 Jungle Gym

In the subitizing game *Jungle Gym*, children choose stuffed animals with the same number of dots on their shirts to dangle on the monkey bars together. Their first task is to place a target number of objects onto a stuffed animal’s shirt, one object at a time. In this way, children set up the groups of dots that will be seen on the animals in the next scene. Children then drag stuffed animals from the ground to dangle from the various monkey bars. Only stuffed animals with the same number of dots on their shirts can dangle together. When a child attempts to place a stuffed animal with a different number of dots from the animal that is already dangling, the incorrect stuffed animal snaps back to the ground. When all animals have been placed with similarly dotted animals, the chains of stuffed animals begin to sway. Children then shake the iPad to cause the stuffed animals to fall onto a trampoline on the ground, and they start the next level.

The challenge in creating an exploratory game for assisting subitizing learning was that the time feature, which is crucial to subitizing, needed to be taken away so that children could have open-ended play, as a sandbox game requires. To address this challenge, we created this game with the goal of building foundational components of subitizing by allowing children to explore the essence of number and the similarities of groups of the same cardinality while not imposing any type of time constraints.

3.3.2 Park Play

In the equipartitioning game *Park Play*, children interact with four settings in a park area, completing equiparititioning tasks in each setting. In a grassy area, children drag equal numbers of hula hoops onto their friends’ mats. In the shade of an apple tree, children shake the iPad to make the apples fall and then drag the apples into baskets to distribute them equally among friends. In the tree-top, children slice a pie and distribute the pieces equally among birds. In the sky, children move bubbles freely to form clouds and explore the idea that objects are divisible into units. Children move easily from one setting to another, which allows them the freedom and flexibility to switch between tasks and determine their own game play and learning trajectories.

Part of the challenge of creating *Park Play* was determining game mechanics that allowed for exploration of the fundamental components of equipartitioning. To this end, after many prototypes of equipartitioning games, we settled on the four worlds, with each addressing a different component of the math curriculum (such as the idea that there are many ways of distributing the same number of objects to different groups).

4. SIGNIFICANCE

The goal of this paper is to share our production process and apps in an effort to help other efforts to design tablet games that preschoolers can easily interact with and learn from. This development and research approach to designing games seeks to ensure that games, or learning activities more broadly, are aligned to target concepts or learning goals. In addition, this framework can facilitate successful partnerships between researchers and developers.

5. ACKNOWLEDGMENTS

This research was funded by the National Science Foundation (DRL-1119118). Any opinions, findings, conclusions, or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

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