NSF Research Report for infinut Math

1548029 - Conceptual Math Learning using Manipulatives in Touch-based Games

Summary

infinut built and researched the Kindergarten Math application with 30 lessons consisting of 20 different math mini-games. The application covers the full common core math curriculum for Kindergarten. It contains visual and interactive math exercises that develop deep understanding of elementary math concepts. Many contextual voice hints instruct and explain - helping students learn.

An efficacy pilot study was conducted with 25 students in the play group who played the application for 3 months and 19 in a control group that did not play the application. At the beginning of the study, the play group was behind the control group in math. By the end of the study, the students in the play group had caught up to the students in the control group. Playing a lesson covering a specific topic in the application, resulted in a large improvement in the student's test scores for that topic. Students in the lowest 10th percentile showed an improvement of 24 percentile points more than similar students in the control group, showing that Kindergarten Math is an effective tool for learning.

Team

The following team members worked on the project. Below are their names and primary responsibilities:

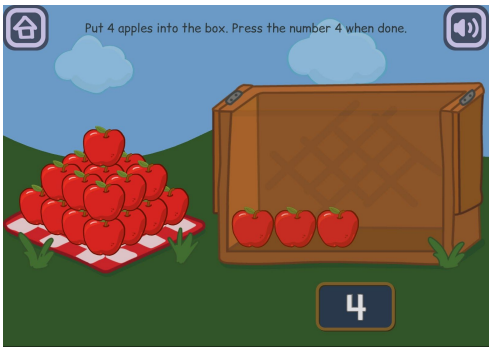
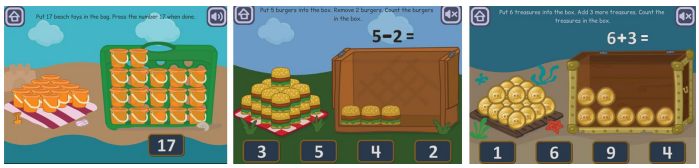
1. Ana Redmond
   Principal investigator and lead developer.
2. Susan Lin
   Curriculum design and research study.
3. Barbara Krug
   Art direction, game design and graphics.
4. Shima Akhvanfarid
   Android and game development.
5. Mike Wall
   Audio recording and processing.
6. Sherri Bealkowski
   Commercialization and educational sales advisor.
7. Christy Ballweber
   Statistical consultant

The team worked together at a collaborative office space in Kirkland, WA to build a commercializable first release of Kindergarten Math. In Phase II, the same team will build first to fifth grade math.

The research study was conducted at [redacted] in Lake Washington School District. We are very grateful to the principal and teachers at the school for their time and effort on behalf of their students, and their participation in the study.

Product - Kindergarten Math application

The Kindergarten Math application consists of 30 lessons, organized by topics of increasing difficulty. Within each lesson are 20 exercises to teach math content and provide practice opportunities. Each exercise is defined using a mini-game.The mini-games use color, animated graphics that ask the students to physically manipulate items on the screen. There are 20 mini-games in the application. A mini-game can be used in many different types of exercises. For example, moving apples into a box functions as a counting manipulative. The same manipulative is used in addition by moving the first quantity of apples into the box and adding in the second quantity. It is used in subtraction by moving the first quantity of apples into the box and removing the second quantity. The mini-games in Kindergarten Math are shown below.

<table>
<tr>
<td> 
</td>
<td>Game: Pack in box
Move objects into a box to learn quantities.
Themes: Picnic, Treasure, Beach
 

Exercise types: Addition, Subtraction, multi-operand addition.</td>
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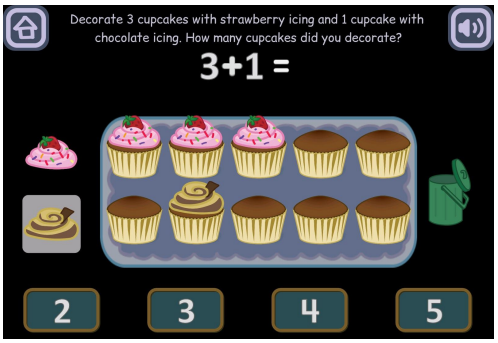
<td> 
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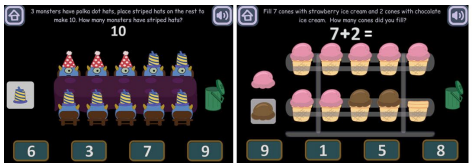
<td>Game: Decorate cupcakes
Count and add with manipulatives.
Themes: Cupcake, Monster party, Ice Cream
 

Exercise types: Addition, Subtraction, Make 10, Commutative addition.</td>
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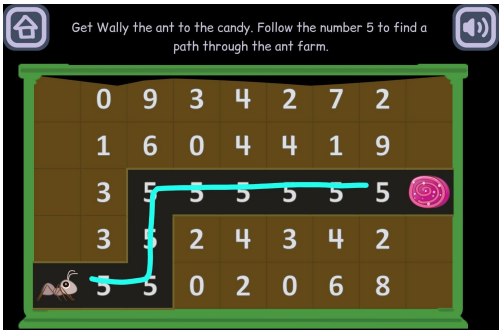
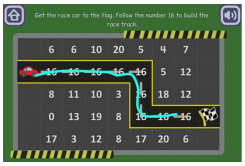


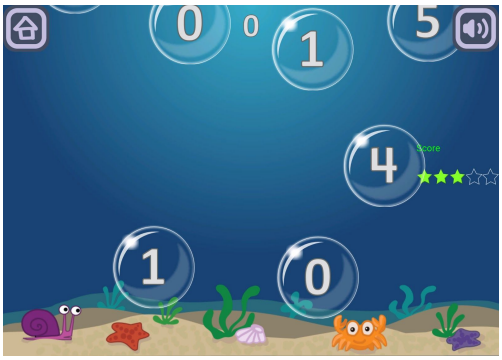
Game: Numbers Maze

Tactile touch for number recognition.

Themes: Ant Farm, Race Track



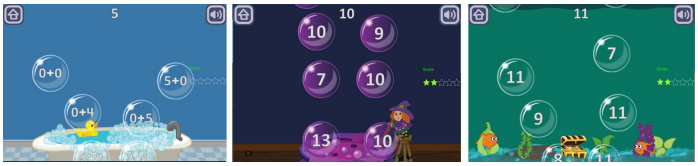
Exercise types: Number Identification



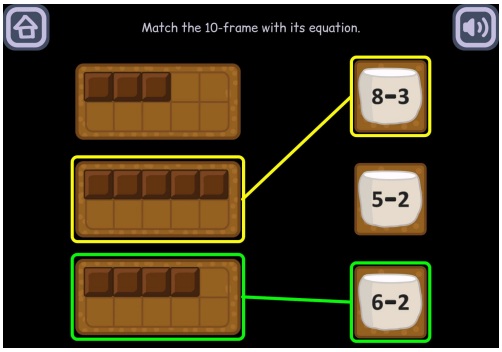
Game: Bubble Pop

Tactile touch for number recognition.

Themes: Seafloor, Bubble Bath, Caldron, Fish Tank



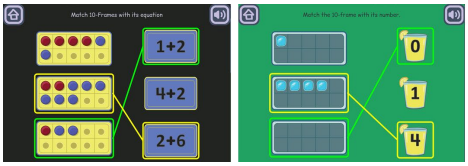
Exercise types: Number Identification, Mental addition, Mental Subtraction.



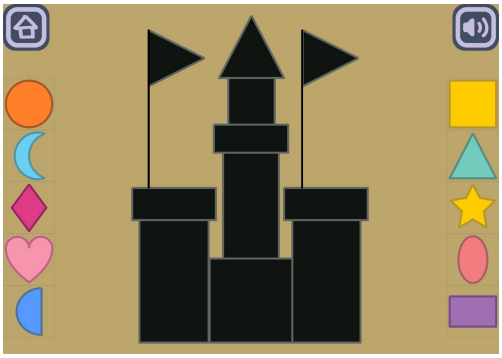
Game: Match Ten

Match a quantity with its visual 10-frame representation.

Themes: S'mores, Pegs, Lemonade



Exercise types: Representation of large numbers, addition, subtraction, commutative addition.



Game: Shapes Puzzles

Recognize shapes within patterns.

Themes: Castle, Sub, Rocket, Caterpillar (18 in total)

Exercise types: Recognize Shapes

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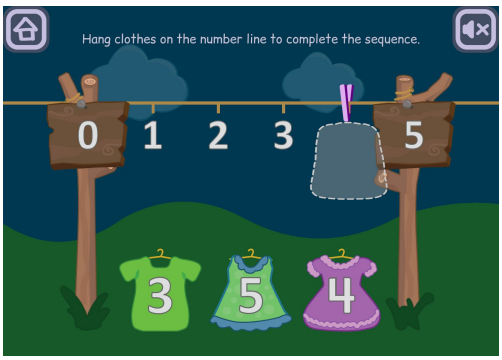
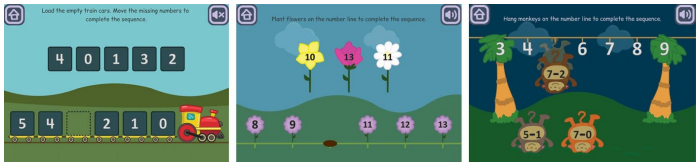
<td> 
</td>
<td>Game: Number Line
Conceptual learning of the number line and sequence.
Themes: Clothesline, Train, Flowers, Monkeys
 
Exercise types: Addition, Subtraction, Number Sequence</td>
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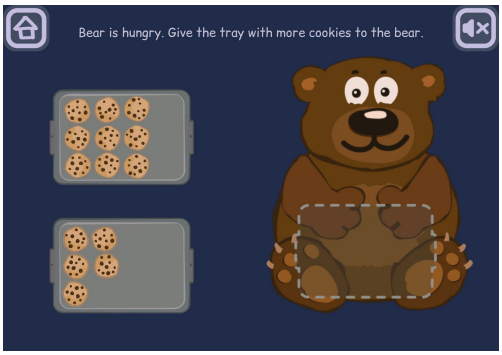
<td> 
</td>
<td>Game: More
Compare and evaluate quantities and volume.
Themes: Bear, Watercan, Milk
 
Exercise types:Compare quantities and volumes</td>
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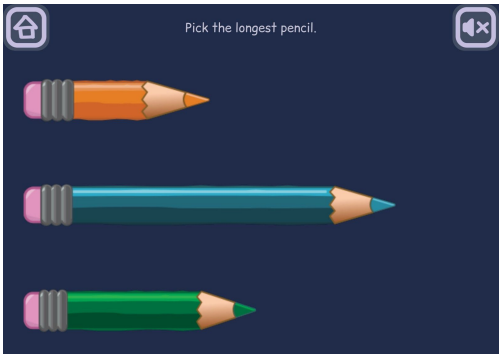
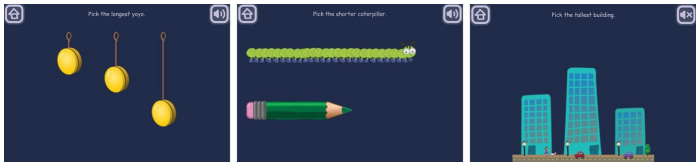
<td> 
</td>
<td>Game: Lengths
Compare relative lengths of items.
Themes: Pencils, Yoyos, Caterpillars, Skyscrapers
 
Exercise types: Determine longest and tallest objects</td>
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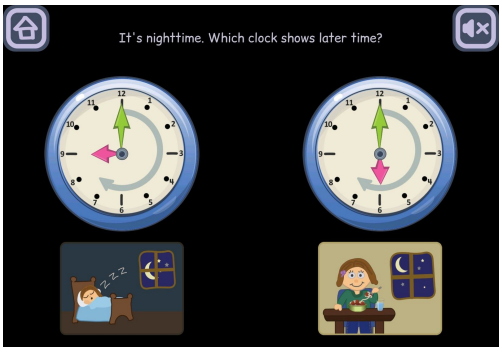
<td> 
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<td>Game: Time of day
Determine relative time with events.

Exercise types: Earlier vs. later time.</td>
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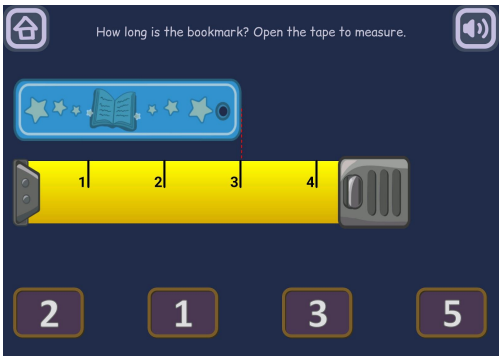
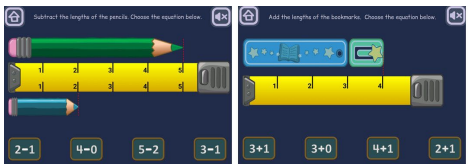
<td> 
</td>
<td>Game: Measure Lengths
Understand uses of quantities in measurements.
 
Exercise types: Measurement, addition sentence, subtraction sentence</td>
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<td>Game: Feed the Monster
Use mental math to get to 10
 
Exercise types: Mental Math for addition and subtraction, Make 10.</td>
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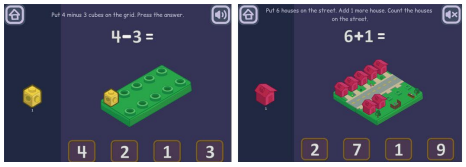
<td>Game: Tens and Ones
Learn place value up to 20
Themes: Blocks, Houses
 
Exercise types: Addition,Subtraction, Place Value</td>
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<tr>
<td> 
</td>
<td>Game: Event Sequencing
Determine what happens first, middle, and last.
Themes: Sand Castle, Robot, Dog Wash, Snowman
 
Exercise types: Sequence Events</td>
</tr>
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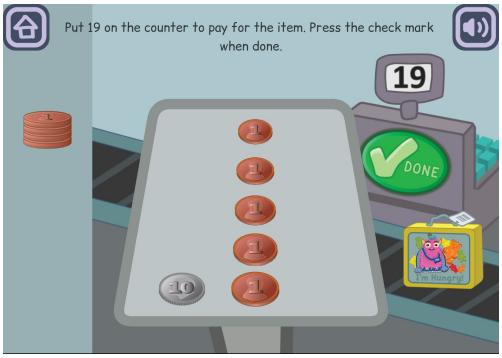	**Game: Shopping** Understand place value using coins with 10 and 1 values. **Exercise types: Place Value, coins, money**
	**Game: Weighing Scale** Understand use of quantities in measuring.  **Exercise types: Heavier, lighter, multi-operational addition using 1s.**
	**Game: Soccer Throw** Tactile learning using manipulatives to count. **Exercise types:Number Identification**
	**Game: Move Mama Duck and her Ducklings** Compare quantities out of a set of objects. **Exercise types: Compare discrete quantities**

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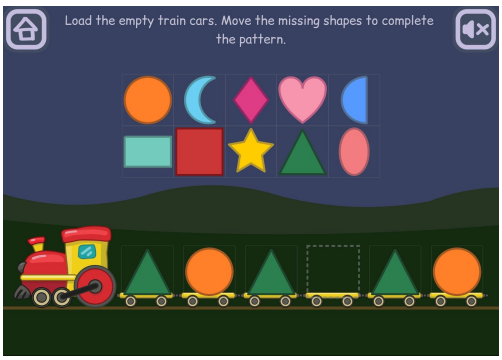
<td> 
</td>
<td>Game: Patterns
Recognize ABAB patterns to develop logical thinking.

Exercise types: Shape patterns, Number sequences.</td>
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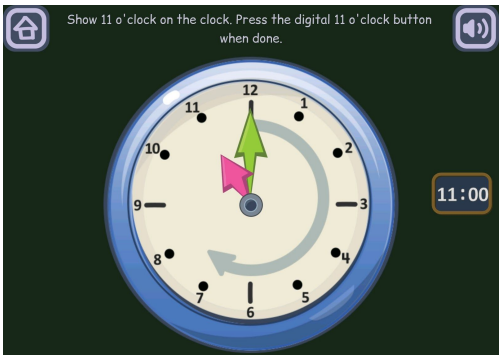
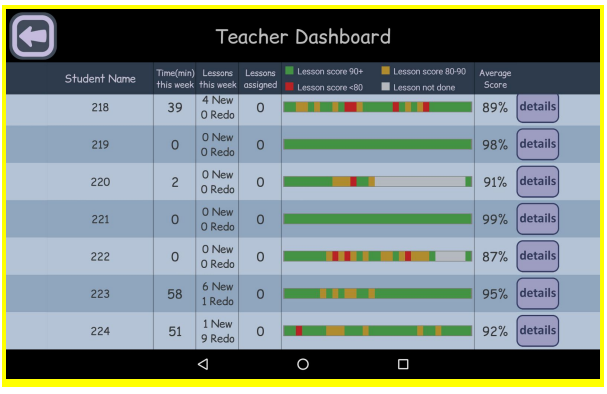
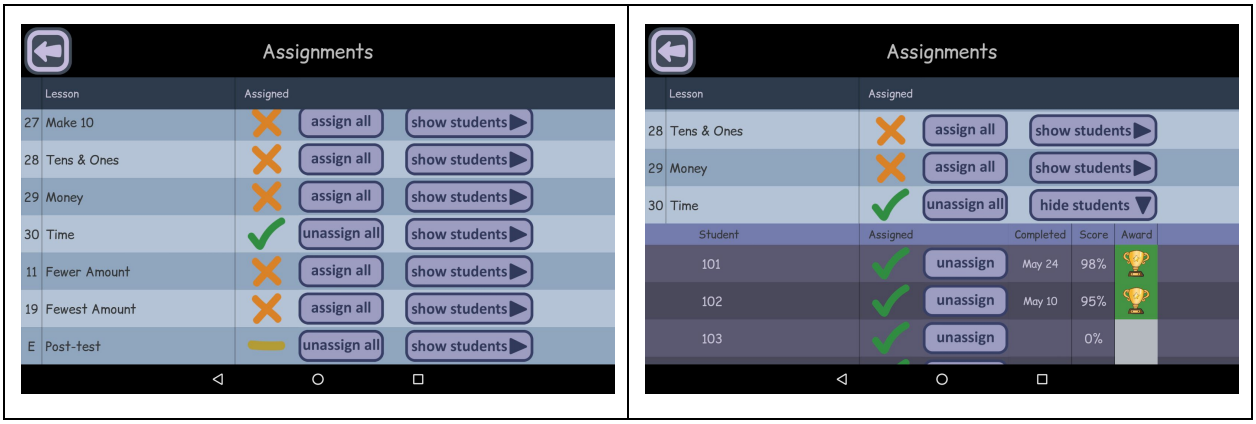
<td> 
</td>
<td>Game: Setting time
Use tactile touch to set the clock face to the right time.

Exercise types:Telling Time</td>
</tr>
</table>

Many brand new mini-games were built during Phase I, resulting in a ready-to-publish Kindergarten Math application. Graphics, audio and many hints and explanations were built within the context of each exercise. We built 5 more lessons than planned for a total of 30 lessons. This provided more practice and better alignment with standards.



We built a dashboard and detailed report of student progress for the teachers. We also added a way for teachers to assign specific lessons to students. This was a much requested feature for teachers to integrate application learning with classroom learning.



Pilot Research Study

Study Participants

Teachers

The three kindergarten teachers in this study are employed at the same suburban elementary school in the greater Seattle area. All teachers have taught kindergarten for numerous years. Two kindergarten teachers joined this study because they agreed that there is a need for supplementary math curriculum for kindergarteners. Currently, their Title I school does not have any math curriculum for kindergarten beyond their main textbook. Additionally, the kindergarten classrooms have limited access to technology. One kindergarten class was the control group, and only completed the pre-test and post-test.

Teachers liked having a math application available to give their students. Students got a choice between a math and a reading application, and hence, more variety of learning. Having tablets during small group instruction gave the teachers time to work with small groups of 3-4 students, while the remaining students continued to learn independently.

Students

The study participants were 25 students from two classrooms at our study site, a public suburban school with grades K-5. The students who played Kindergarten Math were 5 or 6 years old. The students were selected by their teachers on criteria such as unlikely to be absent, and unlikely to be pulled out of the classroom, so they have time to work independently on tablets. A third classroom of 21 students formed the control group. They only played the pre and post tests.

The students appeared to enjoy the Kindergarten Math application and frequently laughed at certain aspects: the graphics, the auditory cues, and the awards at the

completion of each lesson. The students were eager to play the Kindergarten Math application every time the researcher entered the classroom. The students were able to independently play the application, including using headphones and accessing the application through the Nexus tablet.

Research Plan

The research team delivered 25 Nexus tablets to the two kindergarten classes in February 2016. The students became familiar with the tablets before the study began. The Kindergarten Math application was delivered in four waves between February - May 2016. The students played the application two days a week during their Small Group Instruction (SGI) time in the afternoon. Some students worked with paraprofessional aides, some worked with the classroom teachers on specific skills, some completed worksheets at their desk, and the rest played the Kindergarten Math application on the carpet area. The students rotated groups every 15 minutes.

If the students completed the lessons before the next software delivery, they were encouraged to replay previous lessons. The students had minimal supervision; a researcher observed the students playing two days a week but did not intervene unless asked a direct question. The following is the schedule of the study implementation:

Task	**Completed**
Pre-test (control and experimental classrooms)	2/22/16
Milestone #1: Lessons 1-6	2/29/16
Milestone #2: Lessons 7-12	3/21/16
Milestone #3: Lessons 13-21	4/6/16
Milestone #4: Lessons 22-30	5/2/16
Post-test (control and experimental classrooms)	6/1/16
Teacher Exit Interviews	6/15/16

After delivering of the post-test, the development team completed a full test cycle and bug fixes. They also added new animations and effects to keep students engaged.

Progression of Learning

All 25 students in the study progressed easily through the first six lessons, where the standards covered Pre-K topics such as shapes, colors, number identification, and more or less comparisons.

The second delivery of six lessons covered topics such as adding and subtracting numbers 0 to 5, mental arithmetic, commutative property, and multi-operand operations. Here, there were distinctions between students progression among both classrooms. Half (12) of the students were able to complete the second delivery of six lessons within the three week timeframe. All students received approximately equal time of tablet use. Many students made mistakes in lessons on topics such as subtraction, measuring and mental math. The audio-visual feedback provided in the application helped the students learn from their mistakes and continue playing.

The third delivery of 9 lessons afforded students the opportunity to add and subtract numbers below 10 and add-on or subtract by 0, 1, or 2 units. Within the three week timeframe, half of the students had completed all the lessons. The other half were well on track to finish the lessons. There were a couple of students who struggled with single digit equations. The real-time dashboard provided teachers the opportunity to understand their students individual needs and respond to them.

The final delivery of 9 lessons taught students values up to 20, supported their conceptual understanding of combinations that make up 10, and included comparisons of discrete quantities and analog clocks. Students shared that they know their numbers to 20, so these lessons were easy. Others were found to repeat lessons they have successfully completed. Overall, students performed well on analog clocks and using dimes and pennies.

All students played the application for roughly 1/2 hour per week for 13 weeks. 17 out of 25 students completed all the lessons, 8 did not complete all the lessons, given the time constraint.

Technical problems

- Batteries were draining faster for some devices. We checked data usage on the devices. Our application was using background data. Suspect listeners left open on Firebase poll constantly, causing battery drain. Fixes in code to unregister listeners on pause were done with milestone #2. The application’s background

data usage fell to nearly 0. We also turned off all playstore updates that could be causing background battery drain. This resolved battery drain issues.

- Wi-fi is on guest wi-fi. The guest wi-fi kicks out the network connection on the tablet periodically, and has to be reset by a researcher or teacher. The teacher sent email to the help desk requesting permission to put the tablets on the school's internal wi-fi which is password protected. The district did not allow us to put the tablets on the school wi-fi, since, they do not consider these devices approved by the district. We turned on local data persistence on Firebase to correctly save data even with intermittent network connectivity. But, the inconvenience of having to reset network connections periodically remained.

Usability improvements

infinut piloted the Kindergarten Math application in two local kindergarten classrooms and obtained continuous feedback from teachers and students. As such, based on this feedback, we modified some aspects of the application to improve its usability. Each subsequent milestone included adjustments to improve teacher and student usability of the application. Some examples are:

- After Milestone #1 - New instruction - Open the tape longer - student confused by repeating 'open the tape to measure', since tape was already open. Added the sound for 'Open the tape longer' instead when tape is partially open.
- After Milestone #1 - Prevent input when showing what mistake was made - students impatient, and do stuff while mistakes are being shown, which stops them from understanding their mistake and learning from it. Modify application feedback to students to scaffold conceptual understanding, and give more defined audio on the mistake made.
- After Milestone #2 - Dashboard - Added time and mistakes. Meeting with teachers helped us understand that they were looking for weekly usage in terms of how much time was spent and how many lessons were completed. Investigators did not previously realize this was needed information for teachers to understand if their students are spending enough time playing the application.
- After Milestone #2 - Weights - Observed students having extra difficulty with these problems. Simplified the weight measuring game to have only one type of weight. Added more audio and visual hints to tell the students to add or remove weights to balance the scales.
- After Milestone #3 - Added feature to application to allow teachers to assign specific topics to students. The need for this feature was realized after interviewing teachers from other schools for the I-Corp bootcamp. This completely new feature was added to the originally planned work.

- After Milestone #4 - Increased the speed of bubbles for the number bubble pop since students mentioned it was too easy. Reduced the speed for equation bubble pop. The data showed that students were having difficulty computing the sums fast, and need it to be a little slower.
- After Milestone #4 - Students were having problems understanding that the 10 cubes stacked on one another implies 10 cubes, not 1 tall cube. So, each individual cube is now numbered in the template for the 10 stacked cubes to show it clearly that it is 10 cubes stacked on top of each other.

Data Analysis

Data Collection

A 20 question pre-test was administered to 46 Kindergarten students, 25 of whom are in the play group, and 21 of whom are in the control classroom. The pre-test covered topics from Pre-K to 1st grade standards to capture the extent of student knowledge in math. The pre-test was administered in February, which is five months into the school year, so the students had exposure to at least half of the Kindergarten Common Core State Standards. A similar 20 question test was administered to the kindergarten students in the play and control groups at the end of the study on May 31st.

The application also collected continuous data for the play group on how many mistakes they made for a particular exercise, how much time they took to complete an exercise, how many lessons they completed, and how many lessons students played more than once. Students ability to read did not have an impact on their ability to play the Kindergarten Math app or pre and post-tests, since, all instructions were through audio.

Analysis and insights

Data was analysed for 25 students in the play group, and 19 students in the control group. Two students from the control group were eliminated because of missing pre or post-tests. A total of 18 exercises were considered for the data analysis. 1 exercise was eliminated due to a coding error in the pre-test, and the fractions exercise was eliminated since it is outside the scope of the common core standard for kindergarten math.

Learning Gain

For the play group alone, a paired t-test (pre- Vs. post-), with post test scores being for lessons completed showed statistically significant ($p < .001$, $d=1.24$) learning gains. The effect size for this analysis ($d = 1.24$) exceeds Cohen's (1988) convention for a large

effect (d=.80). This means that playing a lesson covering a specific topic in the application, resulted in a large improvement in the student's test scores for that topic.

Percentile Gain

The play group started with a lower 50th percentile score, i.e. overall the play group consisted of students that were behind the control group, but, are now caught up.

Group	Pre-test 50th percentile score	Post-test 50th percentile score
Play Group A	77%	83%
Play Group B	77%	83%
Play Groups A and B	77%	83%
Control Group C	83%	83%

Though not statistically significant, this indicates that Kindergarten Math may help students who are behind in math to reach parity with the rest of their peers.

Students in the lowest 10th percentile in the play group saw their scores go up by an average of 20%. Students at the same level in the control group, saw their scores go up by an average of only 14%. Many of these students were English Language Learners (ELL). This suggests that Kindergarten Math is an effective learning tool for students who are behind in math - irrespective of their language skills.

Group of Students	Effect Size*	Percentile Gain**
All students in play group vs all in control group.	0.17	7
Play group students in lower 10th percentile in play group vs. same in control group.	0.64	24

* Cohen's D Effect size calculated per https://soltreemrls3.s3-us-west-2.amazonaws.com/marzanoresearch.com/media/documents/pdf/AppendixB_DTLGO.pdf

** Percentile gain implies that being assigned to the play group would have led to this percentile point increase in the percentile rank for the average student in the control group.

Replaying lessons in the application

Students could go back and replay any previously completed lessons. Of the lessons students replayed, they made the largest improvement in lesson scores on subtraction lessons such as -

- Learn to subtract numbers up to 5.
- Practice subtracting numbers up to 5 mentally.
- Learn to subtract by 0 or 1 for numbers upto 9.
- Learn to subtract by 6, 7 or 8 for numbers upto 9.

Through the feedback given by the application on their mistakes, students progressed in their learning.

Student stories

Student 220 and 223 in the play group, and 305 in the control group started with the same pre-test scores of 61%. 305 was not in the play group and gained 0% in their post-test score. 220 completed half of the lessons and gained 11% in the post-test score as compared to the pre test. 223 completed all of the lessons and gained 28% in the post-test score.

305 - Not assigned to play group - no improvement in post-test
220 - Half of lessons completed - 11% improvement in post-test
223 - All lessons completed - 28% improvement in post-test

Student 108 started with the lowest score of everyone in the study. But, 108 was improving their score even with only half the lessons completed. He liked to go back and replay some of the lessons. This self-directed repetition gives the students an opportunity to go back to clarify and build concepts. Student 108 and Student 315 had the lowest pre-test scores in the play group and control group respectively. The student with the lowest pre-test score in the play group improved their score by 22%, while the student with the lowest pre-test score in the control group improved their score by half of that, i.e. 11%.

Student 221 replayed the most lessons, completing total 40 lesson replays. They were motivated to remove the red or yellow status bars. Yellow for a given problem implies 1 mistake, and red implies 2 mistakes in the exercise. Student 221 received the highest overall score in the application of 99.92%. They also increased their score from 94.44% in the pre-test to 100% on the post-test.

Conclusion

The objectives as stated in our Phase I proposal and the corresponding Phase I achievements are:

Objective 1

We will build Kindergarten Math School application. It will contain 25 lessons using 20 different mini-games. Each lesson will contain 20 exercises built using appropriate games. The lessons will be aligned with the school curriculum, and will increase in difficulty as the student progresses.

Met and exceeded
With this project, we built and will soon release the Kindergarten Math application - first for homeschool customers, and soon after, for schools. We established the team, the agile development process, the research pilot and a commercialization plan. To be competitive in the market for subscription-based educational content, we will continue to build first grade to fifth grade math.

Objective 2
Secondly, we will build a dashboard for the teachers to see the progress of all of their students at a glance. The teacher will be able to deep-dive in the data to see how many attempts it took a student to complete any given exercise.

Met and exceeded
Along with building a dashboard, we also provided a much requested feature to let teachers assign specific lessons to students. Teachers know best how to engage and encourage the students to keep advancing their learning. Both data and actions to take based on that data are required in software applications used in classrooms. These features make our math software very appealing for teachers and schools.

Objective 3
We will conduct a study in a kindergarten classroom at a school to determine usability and efficacy of the Kindergarten Math School application.

Met and exceeded
In addition to improving the usability of the application with the study, we also showed that the Kindergarten Math application is effective in improving learning outcomes for students that are behind in math. We also took the feedback gained from observing the students playing the application, and incorporated it into the application continuously. Given the attenuated time frame of Phase I, it would be valuable to conduct a study for a complete school year. We plan to continue to research the usability and impact of kindergarten to 5th grade infinut math.

We completed all three objectives for Phase I.

Students who fall behind in math by 1st grade don’t catch up (Geary et al., 2013). infinut is on a mission to improve children’s learning in a fun and engaging way. By reducing the gap between student achievement in the short term and making math learning fun for all elementary school students, not only can we help students catch up, we may also help narrow the STEM employment skill gap in the long term.