The effects of an online collaborative elementary math program using team-based games to improve student math achievement, attitude and motivation.

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Abstract

The U.S. mathematics education system is failing to produce enough technically skilled workers for it to stay globally competitive. One of the key problems is that U.S. students are not learning the foundational math skills they need during the elementary school years. This research study evaluated the effects of an online collaborative elementary math program using team-based games (Sokikom) to improve student math achievement, attitude and motivation. The research questions focus was on achievement, attitude and motivation. Sokikom, (pronounced so-kee-kom) is an online collaborative math program developed through grants from the Institute of Education Sciences (IES), where elementary students help each other learn through a team-based game as well as adaptive, independent learning games. Though a quasi-experimental design, the researchers studied the effects of using Sokikom for 1 year in 2 elementary schools in Oxnard, CA. Specifically, effects on students' mathematics achievement as measured through the end-of-year CA state test. The results showed that there was a significant and positive association between the number of new lessons mastered and math *achievement as measured by the California Assessment of Student Performance and Progress (CAASPP) scores ($p<.0001$), which use the Smarter Balanced Assessment. For each additional new lesson mastered a student's CAASPP math score increased 0.58 points. Notably the change in mean on the CAASPP score and the students' intrinsic motivation to learn math. End of study data showed students that used Sokikom reliably, had significantly higher CAASPP math scores (18% higher) than other students, independent of teacher or school. In addition, students that used Sokikom reliably had more than twice the amount of students that significantly improved motivation and attitude toward learning mathematics compared to other students independent of teacher or school. The research study also examined the effect reliable-use of Sokikom had on positively changing student math motivation and attitudes for students who find math difficult and boring and students who are curious and excited about math. The latent transition analysis(LTA) findings showed a higher probability of transitioning from the subgroup that found math difficult and boring to the subgroup that were curious and excited about math was for students who used Sokikom reliably, suggesting that Sokikom may have had a positive impact on students' math motivation. For the treated group, the probability of transitioning from the subgroup that found math difficult and boring to the subgroup of students who were curious and excited about math was 0.29, from Time 1 to Time 2. By contrast for the intent to treat group, the probability of transition from the subgroup that found math difficult and boring to the subgroup of students who were curious and excited was 0.14, from Time 1 to Time 2. In general, this research study found that regular use of an online collaborative elementary math game program (Sokikom) by elementary students has the potential to improve math achievement and provide positive motivation in the learning of mathematics.*

Keywords: online collaborative games; elementary math; team based games; elementary student math achievement; attitude; motivation; assessment

1. High level challenge

President George W. Bush convened the National Mathematics Advisory Panel (NMAP) in April 2006 and this group of scholars, educators, and policy makers reminded the nation of its illustrious mathematical past while also providing a stern warning for the future generations:

During most of the 20th century, the United States possessed peerless mathematical prowess—not just as measured by the depth and number of the mathematical specialists who practiced here but also by the extent of mathematical education in its broad population. But without substantial and sustained changes to its educational system, the United States will relinquish its leadership in the 21st century. (NMAP, 2008)

President Barack Obama continued a focus on improving teaching and learning in the science, technology, engineering, and mathematics (STEM) fields through several initiatives from the White House and the U.S. Department of Education (USDOE, 2015; White House, 2010). For decades' math has mostly been taught using a set curriculum using a textbook or digital equivalent that is nothing more than a slideshow showing mathematics being done. These do not provide interactive or immersive models allowing learner to partake in the doing of mathematics themselves.

In the modern world, a technically skilled workforce is critical—not only to compete and survive in the information-based global economy, but also to underpin national leadership and security (Schacht, 2007). But the U.S. is failing to develop this workforce. For decades, the U.S. education pipeline has not produced the necessary number of students for jobs in the STEM fields—jobs that are outpacing overall job growth by 3:1 (National Science Board, 2008). Porter (2013) points to the US workers' poor performance on an Organisation for Economic Co-operation and Development (OECD) assessment of math skills. He further suggests American teenagers' weak scores on OECD assessments are due to schools' failure to effectively prepare students to excel in mathematics. In the past forty years, over a dozen studies have shown that U.S. students consistently score lower in math compared to many other countries (Baldi, 2007; Crosswhite, 1985; Gonzales, 2004; Husen, 1967; Peak, 1997, Stacy, 2015).

To understand why U.S. students rank so poorly in mathematics, the National Mathematics Advisory Panel (NMAP) investigated why U.S. students rank so poorly in mathematics. Major recommendations of the panel include the need to focus on teaching key math topics in greater depth during the elementary years. The elementary school years are critical in mathematical development as most underlying concepts for mathematics are learned then. Elementary level math introduces students to mathematical concepts they will use in subsequent math classes and a multitude of other classes—not to mention various other areas throughout their lives (Ma, 1999). But what happens when students don't understand these math concepts during the elementary school years? Unfortunately, they generally get left behind as their math deficiencies compound through years of subsequent math classes (NMAP, 2008). This is what's happening in our current math education system.

In many classrooms, teachers have a set math curriculum that is usually taught through a textbook or digital equivalent that is nothing more than a slideshow *showing mathematics being done*. Textbooks do not provide interactive or immersive models allowing learners to *partake in the doing of mathematics themselves* (Hess, 2011; Reys & Thomas, 2012). Students are often expected to develop mastery in math topics through completing problem sets within the textbook or corresponding workbook. This is problematic for many reasons. Teachers generally assign the same set of problems to the entire class, which does not address students' unique needs. Next, problem sets are often abstract and devoid of context. Students can complete these sets without understanding real world relevancy. Furthermore, problem sets suffer from delayed feedback, as students generally don't find out which mistakes they've made until one or more classes later. Even though students may care deeply as they grapple with their homework, by the time they get it back, the learning moment has often passed. Finally, problem sets under-utilize group learning even though recent research documents that social and intellectual support from peers and teachers is associated with higher mathematics performance for all students (NMAP, 2008). If these problems are left untreated during the elementary school years, they are likely to lead to poor student performance in math standards and development of anti-math attitudes in later schooling and life (Loveless, 2003). This has resulted in a much larger problem—the U.S is not producing enough technically skilled workers (National Science Board, 2008). Consequently, this may jeopardize not only the U.S. economy, but also national leadership and security (Schacht, 2007).

2. A new model for mathematical learning

There is a growing body of research to support the hypothesis that games can address many of the challenges in the current math education system (Eck, 2006; Prensky, 2001; Randel, 1992; Shaffer, 2005; Shute, 2011, Blankson, A. N., & C. Blair, C. 2016). This empirical research includes meta-analysis of the instructional effectiveness of games compared to conventional classroom instruction. This research has consistently found that games promote learning across multiple disciplines and ages. Software affordances within games can provide learning opportunities not possible in the typical classroom, limited as it is to the technology of the book, the white board, paper, and perhaps physical manipulatives. The world of the computer includes analogues of all those features and in addition offers many affordances that the physical world, including manipulatives, cannot (Ginsburg, 2014). High quality computer games can immerse and engage elementary students in a 'microworld,' an environment artificially constructed to embody basic mathematical ideas and skills and to offer powerful tools to do significant mathematics (Hoyles & Noss, 2009; Papert, 1980. Park, 2016). Furthermore, software can enable elementary students to develop 'situated abstraction' (Hoyles & Noss, 2009), the kind of synthesis between the everyday and the formal. Using tools, making connections between different types of objects, models, symbols, and concepts, and receiving immediate feedback, learners can develop a deep understanding of abstract concepts.

Most of the educational games for mathematics that currently exist, however, miss the mark. Much of the available mathematics software, including games, can be placed into one of the following three categories: drill, edutainment, or free exploration environments (Clements, 2004). For example, drill-based games are little more than a glorified, but efficient, worksheet with emphasis on practice and repetition of procedural tasks. Instruction, scaffolds, and helpful feedback tend to be absent. Edutainment games are often connected to popular children's television shows, using familiar, well-loved characters to initiate and maintain interest. Although perhaps fun and interactive, their limited content and crude pedagogy typically provide little to no educational value (Ginsburg, 2014). Games with free exploration environments can offer opportunities for more profound learning and discovery of deep mathematical concepts. However, these environments tend to lead to superficial understanding (Sarama & Clements, 2002). Additionally, children may lose interest unless given a specific task to complete (Clements & Battista, 2000, Mishra, K., & Vasanta, D., 2016). Many publishers have recognized the importance of research as a marketing tool and, therefore, advertise their software as 'research-based,' and thus of high quality. This claim, however, is often questionable, as research is seldom used in meaningful and effective ways during the development process (Sarama & Clements, 2002, Mohsenpour, et al. 2015). On the other hand, the affordances provided by digital games, especially those that offer multiplayer collaborative group learning, can provide these experiences along with a multitude of other benefits not possible otherwise such as: self-paced, adaptive content, real-time collaboration with peers, immediate feedback and instruction when needed, and virtual manipulatives. In addition, games are far more engaging and captivating to students than textbooks. However, how effective are games at producing learning results that matter to key stakeholders in the current education system? Furthermore, how can games fit into the instructional models used in classrooms?

A new model for the development of high quality research-based educational software for elementary students is called for (Ginsburg, 2014). Mathematics instruction for elementary students should

1. Encapsulate math in contexts that engage students and allow them to partake in the doing of mathematics.
2. Give students the ability to try different approaches to challenges in an environment that minimize the significance of errors, and rewards exploration and discovery.
3. Present math challenges that adapt to the learning level for each student.
4. Facilitate and encourage collaborate learning through team-based learning experiences as well as independent learning.
5. Provide immediate feedback to players on problems and track players' progress over time,
6. Align with both the Common Core Mathematics Content Standards and the Common Core Standards for Mathematical Practice.

3. Sokikom

Sokikom, pronounced (so-kee-kom), has synthesized these goals to develop an online collaborative K-5 math program where students help each other learn in a team-based game as well as being able to learn independently. Initially developed through SBIR grants (http://ies.ed.gov/sbir/sokikom.asp) from the Institute of Education Sciences (IES)—a research entity within the U.S. Department of Education—Sokikom addresses the above goals in its program through Exploration, Discovery, Application, and Practice (EDAP), a method developed by Sokikom, which is underpinned by the constructivist learning theory (Merrill, 1991; Piaget, 1967) and sub theories of guided discovery learning (Bruner, 1961; Mayer, 2004) and situated learning (Lave & Wenger, 1991), as well as research on the way elementary school students learn math (Baroody, 1989; Bitter, 1994; Bitter, 2008a; Bitter, 2008b; Isaacs, 2001).

The constructivist learning theory argues that learning is an active, constructive process. The learner is an information constructor that constructs knowledge from experiences. New information is linked to prior knowledge (Piaget, 1967). The discovery learning theory uses inquiry-based learning where the learner draws on his or her past experiences to discover facts and relationships in new domains. Students interact in the new domain by freely exploring and experimenting to develop a better sense of the rules. As a result, students may be more likely to remember concepts and knowledge discovered on their own

(Bruner, 1961). However, discovery learning theory has also received criticism for its pure use as an instructional strategy for novices (Mayer, 2004). Since learners can often fail to recognize key principles and rules, Sokikom uses a guided discovery learning model by offering tutorials that guide students on the mechanics behind each game. Many Sokikom games (e.g. Fraction game shown further below) allow students to freely solve problems in multiple ways. However, if students get stuck they are provided with an option to receive hints or an instructional help video which explains how to solve the problem.

The situated learning theory posits that learning is embedded within activity and presented in meaningful contexts through relevant applications (Lave & Wenger, 1991). Social interaction and collaboration are essential components of situated learning (Lave & Wenger, 1991). Sokikom presents mathematics that is embedded within the experience of solving problems (e.g. Measurement & Data game that allows students to put various mass quantities together). Furthermore, recent research documents that social and intellectual support from peers and teachers is associated with higher mathematics performance for all students (NMAP, 2008). Sokikom's games provide opportunities for students to collaborate and compete with each other in real-time as they solve math problems.

Lastly, research has shown that efforts to strengthen formative assessments produce significant learning gains (Black, 1998). Sokikom contains rich formative assessment data through various reports--Common Core Mastery reports, Usage reports, Growth reports. The implementation of the underlying EDAP learning theories within Sokikom enables students to have immersive learning experiences that can't be accomplished in non-gaming environments (Shaffer, 2005, Meylani, 2015).

Sokikom is broken down into four micro-worlds aligning with the Common Core standards for K-5: Fractions, Operations & Algebra, Measurement & Data, and Geometry.

4. A look at Sokikom

4.1 Pre-test

4.1.1 Features

- Students start Sokikom by taking pre-test containing standardized questions in whichever mathematical domain they choose to begin. An example pre-test question for the Measurement & Data domain is shown above.
- Questions start off at a grade 1 level and then progressively become more difficult as students answer questions correctly. If a student has gaps in a series of related questions, the system will exit the pre-test and place the student at the correct starting point to begin individualized and self-paced learning.

4.2 Situated interactive content

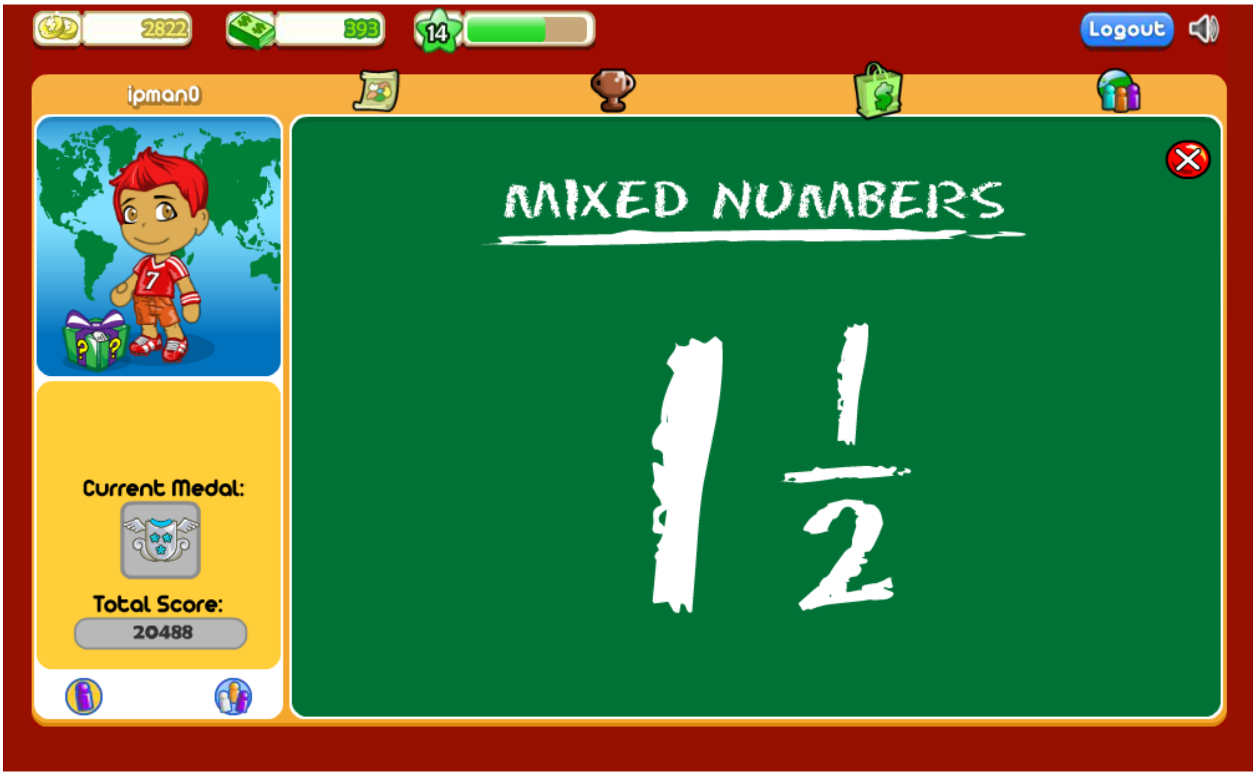
4.2.1 Features

- Sokikom games contain experiential activities that provide students with contextually meaningful learning that is highly visual and interactive.
- In the example above, students start with whole blocks and then split them into various denominations (i.e., fraction pieces) to create the desired amount. Students are free to create any denominations they want and explore what the combination of those denominations results in by seeing the value displayed to the right of the answer box.
- Students are also challenged to combine denominations in different way to solve the same problem. In the picture above, a student is asked to create one-half differently by the "Solve a different way!" that appears below the question.
- Questions are adaptive and self-paced based on student understanding

4.2.2 Research

The situated learning theory posits that learning is embedded within activity and presented in meaningful contexts through relevant applications (Lave & Wenger, 1991). Studies have shown that students learning from application-based mathematics curriculum score higher on math standards than students in other curricula (Isaacs, 2001). At the same time, the discovery learning theory uses inquiry-based learning where the learner draws on his or her past experiences to discover facts and relationships in new domains. Students interact in the new domain by freely exploring and experimenting to develop a better sense of the rules. As a result, students may be more likely to remember concepts and knowledge discovered on their own (Bruner, 1961).

4.3 Instructional scaffolding & pedagogy



4.3.1 Features

● Sokikom uses a guided discovery learning model by offering students instructional scaffolding including videos as shown in the example above.

● If students become stuck on a question they can receive a hint as shown in the bottom left. After answering incorrectly two times in a row, students are shown one way to solve an answer—shown in the bottom right.

4.3.2 Research

Guided discovery has been proven to be more effective than pure discovery in promoting learning and transfer (Mayer, 2004).

4.4 Social learning

4.4.1 Features

● In addition to independent practice, Sokikom allows students to play team-based multiplayer games in which students collaborate and compete in real-time to solve math problems. All interaction takes place in a safe and secure environment.

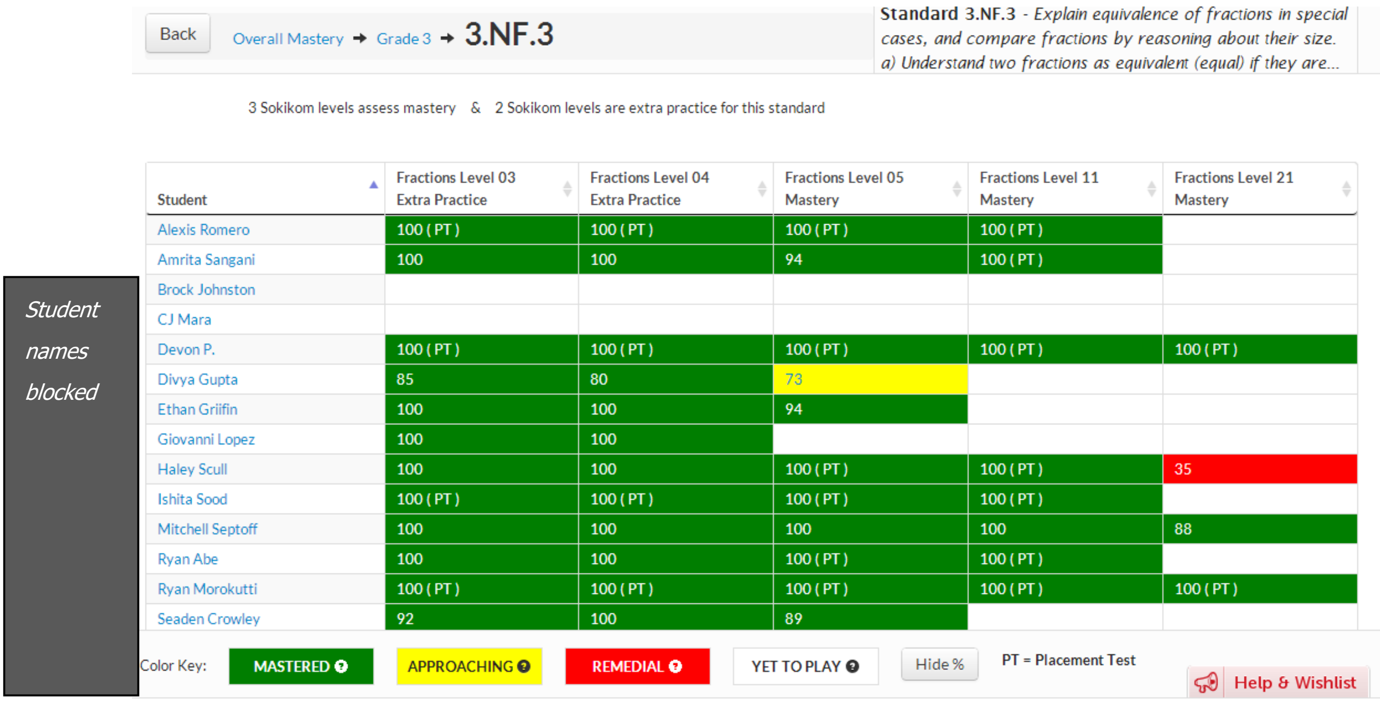
● A single multiplayer game can be played among 2 to 32 students at the same time. There can be an unlimited number of multiplayer games being played at any given time.

● In the example above, students are playing an Operations domain multiplayer game to develop arithmetic fact fluency. Students must solve an individualized arithmetic question and are rewarded if they help their fellow teammates solve their questions.

4.4.2 Research

The situated & social learning theories posit that social interaction and collaboration are essential components of learning (Lave & Wenger, 1991). Furthermore, recent research documents that social and intellectual support from peers and teachers is associated with higher mathematics performance for all students (NMAP, 2008).

4.5 Common Core mastery reports



Back Overall Mastery → Grade 3 → 3.NF.3

Standard 3.NF.3 - *Explain equivalence of fractions in special cases, and compare fractions by reasoning about their size. a) Understand two fractions as equivalent (equal) if they are...*

3 Sokikom levels assess mastery & 2 Sokikom levels are extra practice for this standard

Student	Fractions Level 03 Extra Practice	Fractions Level 04 Extra Practice	Fractions Level 05 Mastery	Fractions Level 11 Mastery	Fractions Level 21 Mastery
Alexis Romero	100 (PT)	100 (PT)	100 (PT)	100 (PT)	
Amrita Sangani	100	100	94	100 (PT)	
Brock Johnston					
CJ Mara					
Devon P.	100 (PT)	100 (PT)	100 (PT)	100 (PT)	100 (PT)
Divya Gupta	85	80	73		
Ethan Griffin	100	100	94		
Giovanni Lopez	100	100			
Haley Scull	100	100	100 (PT)	100 (PT)	35
Ishita Sood	100 (PT)	100 (PT)	100 (PT)	100 (PT)	
Mitchell Septoff	100	100	100	100	88
Ryan Abe	100	100	100 (PT)	100 (PT)	
Ryan Morokutti	100 (PT)	100 (PT)	100 (PT)	100 (PT)	100 (PT)
Seaden Crowley	92	100	89		

Color Key: MASTERED APPROACHING REMEDIAL YET TO PLAY Hide % PT = Placement Test Help & Wishlist

Student names blocked

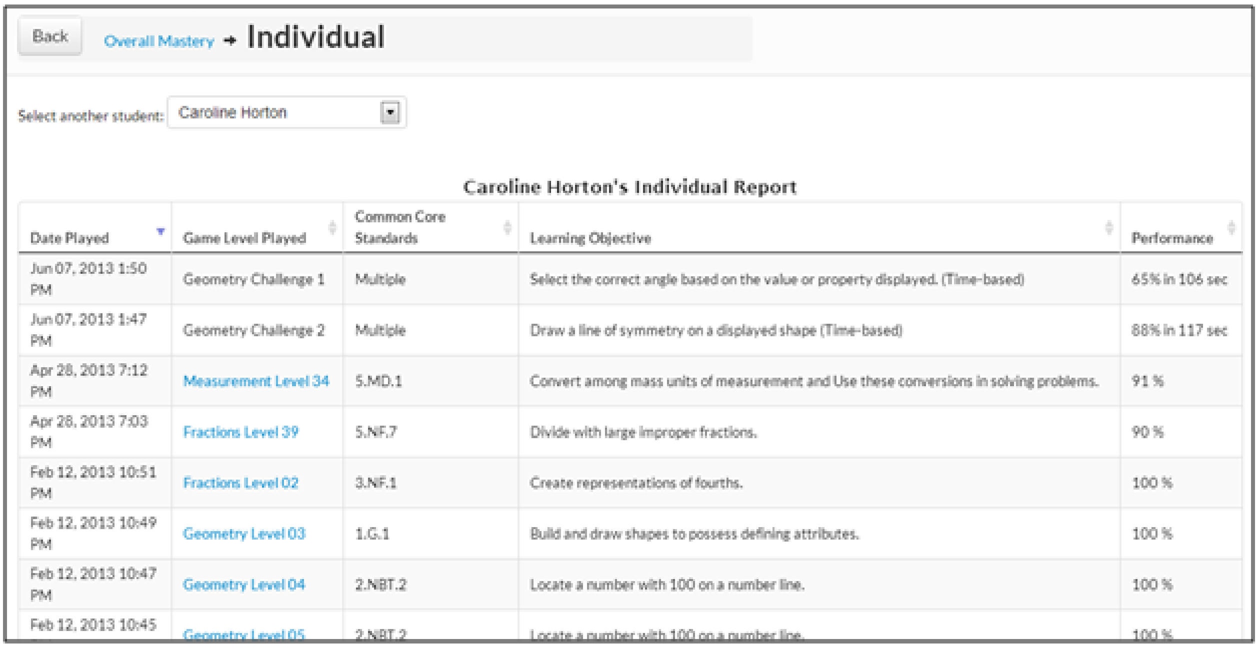
4.5.1 Features

● Sokikom includes in-depth Common Core Mastery Reports that allow teachers to understand how their classroom is performing on each state standard.

● In the example report shown above, a teacher can view a classroom's performance on Common Core Standard 3.NF.3, along with seeing the various Sokikom game levels that provide practice or mastery in that standard.

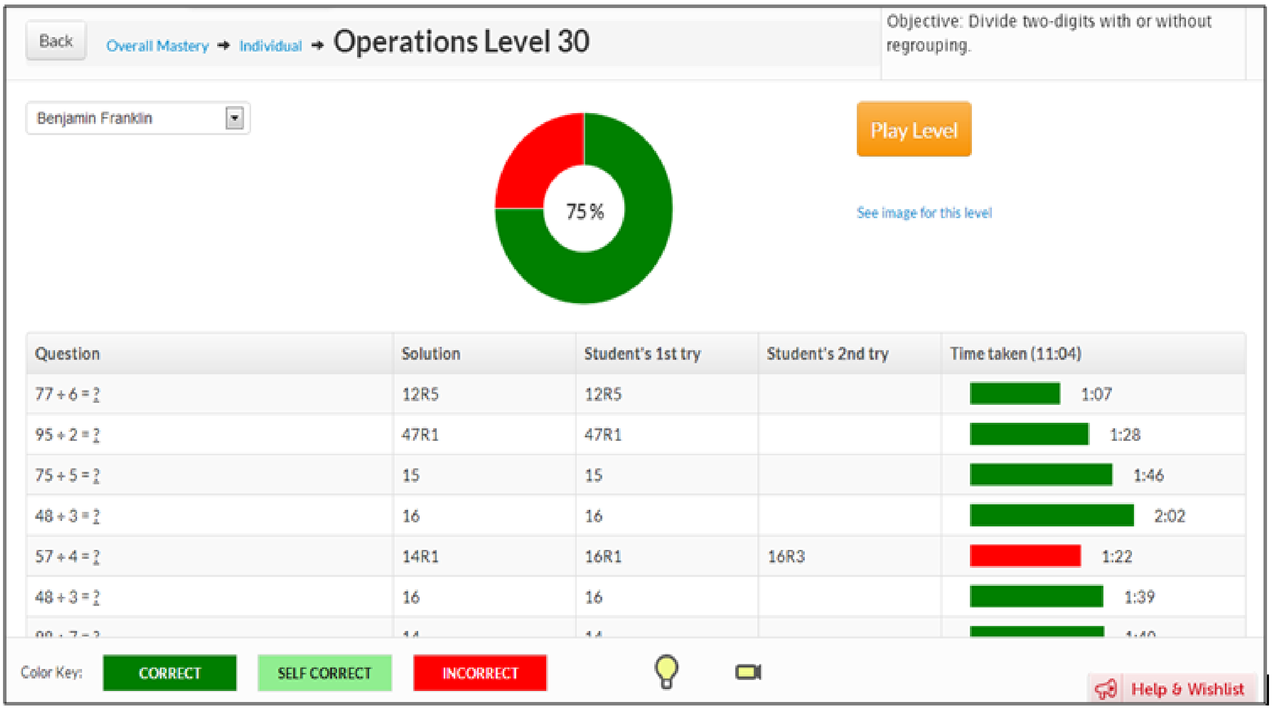
● Teachers can also view how their students are performing across grades 1-6 in related standards as shown in the bottom.

● In addition to all-class progress reports, Sokikom includes in-depth individual reporting features that allow teachers to sort based on performance, work on standard clusters, or when levels were completed. An example individual report is shown below.



Date Played	Game Level Played	Common Core Standards	Learning Objective	Performance
Jun 07, 2013 1:50 PM	Geometry Challenge 1	Multiple	Select the correct angle based on the value or property displayed. (Time-based)	65% in 106 sec
Jun 07, 2013 1:47 PM	Geometry Challenge 2	Multiple	Draw a line of symmetry on a displayed shape (Time-based)	88% in 117 sec
Apr 28, 2013 7:12 PM	Measurement Level 34	5.MD.1	Convert among mass units of measurement and Use these conversions in solving problems.	91 %
Apr 28, 2013 7:03 PM	Fractions Level 39	5.NF.7	Divide with large improper fractions.	90 %
Feb 12, 2013 10:51 PM	Fractions Level 02	3.NF.1	Create representations of fourths.	100 %
Feb 12, 2013 10:49 PM	Geometry Level 03	1.G.1	Build and draw shapes to possess defining attributes.	100 %
Feb 12, 2013 10:47 PM	Geometry Level 04	2.NBT.2	Locate a number with 100 on a number line.	100 %
Feb 12, 2013 10:45	Geometry Level 05	2.NBT.2	Locate a number with 100 on a number line.	100 %

● Teachers are also able to see the exact questions students are missing, how much time was taken to complete the questions and if students sought aid to solve the problem (see example below).



Question	Solution	Student's 1st try	Student's 2nd try	Time taken (11:04)
77 ÷ 6 = ?	12R5	12R5		1:07
95 ÷ 2 = ?	47R1	47R1		1:28
75 ÷ 5 = ?	15	15		1:46
48 ÷ 3 = ?	16	16		2:02
57 ÷ 4 = ?	14R1	16R1	16R3	1:22
48 ÷ 3 = ?	16	16		1:39

5. Rio School District

5.1 Profile

Rio School District began as a one-room school in 1885 and has expanded to include five elementary schools, one kindergarten-eighth grade school, and two middle schools. Currently, the district serves nearly 5000 students living in the El Rio community in the City of Oxnard, California. From kindergarten eighth grades, the average class size is 30 students (Rio School District, 2013).

Table 1 shows the most recently available demographic breakdown of students in Rio School District.

Table 1. *Demographic Characteristics of Rio School District Students, 2013*

Race/Ethnicity	District Enrollment	Rio Plaza	Rio Del Norte
American Indian/Alaskan Native	0%	-	0%
Asian	6%	<.5%	1%
Black/African-American	2%	-	1%
Hispanic/Latino	85%	98%	88%
Multiple	2%	<.5%	2%
Native Hawaiian/Other Pacific Islander	0%	-	0%
White	5%	2%	6%

According to the district's 2012-2015 strategic plan, Enrollment Data from 2011-2012 reflect a socioeconomically disadvantaged population in Grades 2-8 of 65%, with 2,002 students receiving free or reduced lunches. All schools receive Title I funding. Over 20 languages are represented in the district. Approximately 46 % of RSD students are identified as English Language Learners (ELs), 94% of whom speak Spanish as their primary language. During the 2012-13 school year, RSD identified students with IEPs in 8 categories of primary disability. "Specific Learning Disability" and "Speech and Language" were the predominant disabilities reported. Of the 91 students with IEPs for Specific Learning Disabilities, (89%) were Hispanic; of the 138 students with IEPs for Speech and Language, (91%) were Hispanic. As illustrated in the chart, the percentage of Hispanic students in the district was approximately 85% (Rio School District, 2013).

5.2 Current state of mathematics

In mathematics, standardized test results reveal persistent achievement gaps between Hispanic and non-Hispanic subgroups. This difficulty in making AYP towards proficiency in mathematics may be attributed to the increased demands of procedural fluency and conceptual understanding in the Common Core Standards.

At a high-level, Rio School District's top two goals are to make Adequate Yearly Progress (AYP) in English Language Arts and Mathematics. In mathematics, the district plans to provide teachers with increased opportunities for collaboration and professional learning to be able to transition successfully to the Common Core State Standards. Additionally, the district seeks to provide teachers with opportunities to learn to use resources from the Smarter Balanced Assessment Consortium. As part of its long-term plan to improve the teaching and learning of mathematics, the district plans to make strategic changes and investments in instructional materials, standards-aligned instruction, fact fluency and part-whole thinking, number talks and mathematical discourse, mathematical content standards, technology integration, extended learning time, and parental involvement and outreach (Rio School District, 2013).

6. Purpose

The purpose of this study was to investigate the effects of an online collaborative elementary math program (Sokikom) using team-based games to improve student math achievement, attitude and motivation.

7. Research questions

1. What was the effect of Sokikom on student's end of year CA Assessment of Student Performance and Progress (CAASPP) math scores for students who reliably used Sokikom?
2. Is there a significant and positive association between the number of lessons mastered and the outcome on math achievement based on the (CAASPP)?
3. What effect did the reliable use of Sokikom have on positively changing student math motivation and attitudes for:
   (a) students who find math difficult and boring?
   (b) students who are curious and excited about math?

8. Subjects--Descriptive Data

The sample consisted of 1,736 students enrolled in grades 3, 4, and 5 during the 2014-2015 academic year. This sample is composed of two groups of students: a group of 584 students enrolled in two schools where the teacher implemented Sokikom in their classroom; and 1,152 students in four comparison schools that did not implement Sokikom.

The analysis excluded students without baseline score (STAR Math) during the 2013-2014 academic year or without an outcome score (CAASPP Math) following the implementation of Sokikom in spring of the 2014-2015 academic year. Students in the comparison schools who used Sokikom were excluded from the sample.

The final analysis sample consisted of 995 students with valid STAR Math (baseline) and CAASPP Math (outcome) scores. Of the 995 students, 404 students were in the two treatment schools (152 in

Grade 3, 125 in Grade 4, and 127 in Grade 5) and 591 students were in the four comparison schools (194 in Grade 3, 178 in Grade 4, and 219 in Grade 5).

9. Instruments

- California Assessment of Student Performance and Progress (CAASPP) also known as the Smarter Balanced Assessment: For grades 3-5, student performance in math standards will be measured using the CAASPP. These questions have been developed and reviewed by content experts to ensure their appropriateness for measuring standards and fairness to characteristics such as gender, ethnicity, and language. The questions have also gone through multiple stages of field-tests with over 4,000,000 students across the country.
- District administered math assessment (STAR - Renaissance Learning): For grades 3-5, student performance in math standards will be measured using the STAR. This assessment will allow the research team to track growth that occurs outside a student's grade level, i.e. starting either below or going above grade level.
- Student intrinsic motivation survey: Students' intrinsic motivation to learn math was measured by an online survey (Math Motivation Survey) consisting of test items selected from the CAIMI--Children's Academic Intrinsic Motivation Inventory. Academic intrinsic motivation is defined as enjoyment of school learning characterized by an orientation toward mastery, curiosity, persistence, and the learning of challenging, difficult, and novel tasks (Gottfried, 1985). CAIMI has been used in several related studies due to its validity, applicability, and reliability—including a study that revealed that intrinsic math motivation was found to be related to initial and later levels of math achievement (Gottfried, 1990; Gottfried, 1994; Gottfried, 2007; Waters, 2006). All classrooms were administered the Student intrinsic motivation survey in the month of November 2014 and in May 2015.

10. Research Design

The Sokikom pilot was implemented as a quasi-experimental design. Six schools within the district were nonrandomly selected for the pilot during the 2014-2015 academic year. Two schools implemented Sokikom in grades 3-5; initially two comparison schools were chosen, however two additional schools were later added as comparison groups. Teachers from the two schools in the treatment group attended a one-hour professional development training to learn how to use Sokikom in September and October 2015. After this training teachers were given access to the program for their classroom. All teachers were also provided with ongoing support through phone and email as needed. Students in the two treatments schools and the first two comparison schools were administered the Math Motivation Survey prior to Sokikom implementation in fall 2014 (Time 1) and the survey in Spring 2015 (Time 2). Teachers from the treatment schools were instructed to administer the survey prior to using Sokikom. However, due to administrative challenges there were variances in the time the surveys were administered. As a result, some teachers administered them a few weeks after beginning to use Sokikom.

11. Procedures & Data Analysis

The study used a matched comparison analysis to investigate the impact on students' math learning outcomes, attitude and motivation from using Sokikom. Within each grade a treatment student was matched to a comparison student based on their math STAR achievement scores. The match procedure adjusted for differences in math achievement prior to the implementation of Sokikom in order to minimize selection bias. There are potentially two types of bias that can be introduced when trying to approximate a randomized trial by matching students in a treatment group to students in a comparison group. If an exact match is conducted students might be excluded because an exact match could not be found. On the other hand, maximizing the number of students that matched, inexact match may result. Thus, bias might be introduced by both incomplete and inexact matching. Our approach was to assess the effect of Sokikom using three separate matched samples. The first matched sample consisted of treatment students to comparison students that had identical baseline STAR math score. The second matched sample consisted of students from the two groups whose baseline STAR math score was within a half standard deviation below or above the mean STAR score for that grade. The third matched sample consisted of students from the groups whose baseline STAR math score was within a quarter of a standard deviation below or above the mean STAR score for that grade.

Teachers are important in the implementation of Sokikom and students' compliance in using and mastering the lessons. Moreover, students within the same classroom may be more similar in their use of Sokikom and new lessons mastered as well as level of achievement on the CA Assessment of Student Performance and Progress (CAASPP) compared to students in other classrooms. A hierarchical linear model (HLM; Singer, 1998) was used as the most appropriate model to account for variability in the math score and to account for the dependence of observations of students within classrooms.

For each of the three matched samples, the researchers estimated the HLM model to compare differences in CASSPP math score at the end of Sokikom's implementation between students in the treatment schools to those in the comparison schools. First, we estimated the HLM model to compare all treatment students to all comparison students. Such as model answers questions about the overall effects that could be expected from using and mastering new Sokikom lessons. However, compliance in using Sokikom was not perfect between grades and across students in the treatment schools. The amount of time students used Sokikom and the number of new lessons mastered varied across grades and students. Some students in the treatment schools did not login or used Sokikom, some used it very little and did not master any new lessons or mastered just a few new lessons, while some did use Sokikom reliably and mastered a high number of new lessons.

Due to the variance in compliance with using Sokikom across students, we identified two groups of students within the treatment schools: those that used Sokikom reliably and mastered at least 25 new lessons (i.e., actual treated group), and students in the treatment schools that did not use Sokikom reliably and did not master lessons or mastered fewer than 25 new lessons (i.e., intent to treat but not treated). These two groups of students in the treatment schools were compared to address the first research question. The new lessons mastered was also used as a continuous variable in the HLM model to examine whether the number of new lessons mastered was significantly and positively associated with CAASPP math outcome.

The researchers examined students' responses to the Math Motivation Survey using a latent class analysis (LCA) and a latent transition analysis (LTA; Lanza & Collins, 2008). First, LCA identified underlying homogeneous subgroups of students based on their responses on the 15 intrinsic math motivation questions. The responses to the questions were collapsed into three categories: (1) 'not sure', (2) 'not true at all' and 'not very true' and (3) 'sort of true' and 'very true'; the Bayesian Information Criterion (BIC) was used to determine model selection. Second, a multi-group LTA explored transition probabilities from pre-survey (Time 1) to post-survey (Time 2) among students that reliably used Sokikom ('actual treated') and students in the treatment group that did not reliably used Sokikom ('intent to treat but not treated').

12. Findings and Discussion

For each of the three matched samples discussed in the previous section, we estimated HLM models to compare differences in CASSPP math score at the end of the Sokikom implementation. The results from the HLM models that compared all treatment students to all comparison students found no overall effect of using and mastering new Sokikom lessons. After examining the level of compliance in using Sokikom, the researchers found that not all students in treatment schools used Sokikom reliably or mastered new lessons; the time spent using Sokikom varied across grades and students. The researchers believe the lack of full compliance with Sokikom explains the absence of overall effect of using and mastering new Sokikom lessons between treatment and comparison students. There were 404 students in the two treatment schools, of which 159 (39%) were identified as actual treated group (mastered at least 25 new lessons) and 245 (61%) were identified as intent to treat but not treated group (mastered fewer than 25 new lessons). An independent samples t-test showed that there was not a significant difference in the baseline STAR math scores for actual treated group ($M = 550.86$, $SD = 110.91$) and intent to treat but not treated group ($M = 542.63$, $SD = 113.49$); $t(402) = -0.72$, $p = 0.47$.

12.1 Research Questions 1 & 2

The researchers estimated three HLM models to compare differences in CASSPP math score between students in the treatment schools that mastered at least 25 new lessons and students that did not master any new lessons or mastered fewer than 25 new lessons. Table 2 shows the results for the three HLM models. The unconditional model (Model 1) with no predictors was estimated to assess the variance between classrooms (N=23) in students' CASSPP math scores. The intraclass correlation (ICC) was calculated as 0.21 [1113.39/ (1113.39 + 4184.74) = 0.21], which indicates that 21 percent of the variance in CASSPP math score was between classrooms, and the remaining 79 percent at a student level. The intercept of the unconditional model was estimated as 2410.11, which is the average classroom-level CASSPP math achievement score in the 23 classrooms. The variance component between classrooms was estimated at 1113.39 and within classrooms at 4184.74, which suggests that there was more variation among students within classrooms than between classrooms on CASSPP math scores.

The conditional model A (Model 2) estimated whether the reliable use of Sokikom impacted students' CAASPP math scores while controlling for their prior math achievement and grade level. The treatment condition, new lessons mastered, was entered as a dichotomous variable in the model (e.g., 25 or more lessons mastered = 1, and less than 25 lessons mastered = 0). Students' grade and prior math achievement (STAR math score) were included as covariates in the model; the STAR math scores were centered at the classroom mean. The average mean CAASPP score was 2402.14 (SE = 12.19). After controlling for students' grade and their baseline math score (STAR math score), treatment students who mastered at least 25 lessons scored significantly higher (i.e., an increase of 26.17 points) on the CASSPP math compared to those in the comparison group (p <.0001). The inclusion of treatment condition, grade level, and prior math achievement to the model explained 56 percent [(4184.74 – 1831.99)/ 4184.74 = 0.56] of the variation among students within classrooms in CASSPP math achievement.

An alternate model, conditional model B (Model 3), was estimated in which the researchers used the treatment variable, new lessons mastered as a continuous variable along with grade and prior math achievement (STAR math) as covariates. All predictors measured as continuous variables were rescaled at the classroom mean. The results showed that there was a significant and positive association between the number of new lessons mastered and math achievement (CAASPP) scores (p<.0001). For each additional new lesson mastered a student's CAASPP math scores increased 0.58 points. Notably the change in mean CAASPP score associated with new lesson mastered was slightly higher than previous math achievement (β = 0.51). When compared to the unconditional model, Model 3 explained 55 percent [(4184.74 – 1898.03)/ 4184.74 = 0.55] of the within classroom variance in CASSPP math achievement.

Table 2. *Hierarchical Linear Model Results Predicting CAASPP Math Achievement from Sokikom Usage Using Full Maximum Likelihood Estimation (N = 404 students from 2 schools)*

	CAASPP Math Achievement					
	Unconditional Model (Model 1)		Conditional Model A (Model 2)		Conditional Model B (Model 3)	
Fixed Effects	*Estimate*	*SE*	*Estimate*	*SE*	*Estimate*	*SE*
Intercept	2410.11***	7.99	2402.14***	12.19	2410.33***	11.22
Treatment: (Sokikom Lessons Mastered >= 25)			26.17***	5.78		
Grade 4			-10.52	12.46	-3.05	12.83
Grade 5			-3.24	14.87	7.63	14.7
Baseline STAR Math			0.52***	0.03	0.51***	0.03
Treatment: Sokikom Lessons Mastered (Continuous predictor)					0.58***	0.14
Random Effects						
Intercept	1113.39		1632.68		1273.17	

Residual	4184.7 4	1831.9 9	1898.0 3
Deviance	4534.5	4206.9	3928.5
AIC	4538.5	4210.9	3932.5
BIC	4540.8	4213.2	3934.6

Note: ICC = 1113.39/ (1113.39 + 4184.74) = 0.21. AIC = Akaike's Information Criterion. BIC = Bayesian Information Criterion. $*p < .05$. $**p < .01$. ***p<.0001

12.3 Research Question 3

The LCA was used to identify subgroups of students within the treatment sample (*N*=404) on intrinsic math motivation. A three-class model yielded the best model fit. Based on item response probabilities, the three subgroups (latent status membership) were identified as (1) students who find math difficult and boring, (2) students who are persistent and put extra effort, and (3) students who are curious and excited about math. The prevalence of these latent statuses for both groups (the actual treated group and intent to treat but not treated group) is shown in the first half of Table 3. The most common subgroup (latent status) at Time 1 (pre-survey) was the subgroup of students who are curious and excited about math (62% among the actual treated group and 50% among the intent to treat not treated group) followed by the subgroup of students who are persistent and put extra effort; lastly a smaller proportion of the students fell in the subgroup that finds math difficult and boring. At Time 2 the overall patterns is similar to Time 1.

The LTA analysis addressed the third research question: Are students in the treated group who reported math to be boring or difficult more likely to transition to being curious and exciting about math compared to students in the intent to treat but not treated group? Table 3 (bottom portion) shows the results from the transition probabilities in latent status membership between the two groups. The transition probabilities suggest that among the actual treated group, the subgroup who was persistent and put extra effort had about 74 percent chance of being in the same subgroup again at the post survey, subgroup of students who were curious and excited had 69 percent chance of being in the same subgroup at Time 2, and the students that found math difficult and boring had a 47 percent chance of being in that same subgroup at Time 2. For the intent to treat but not treated group, the subgroup who was persistent and put extra effort had about 40 percent chance of being in the same subgroup at Time 2, subgroup of students who were curious and excited had 70 percent chance of being in the same subgroup at Time 2, and the students that found math difficult and boring had 62 percent chance of being in that same subgroup at Time 2.

The LTA results showed a higher probability of transitioning from the subgroup that found math difficult and boring to the subgroup that were curious and excited about math was for students who used Sokikom reliability, suggesting that Sokikom may have had a positive impact on students' math motivation. For the treated group, the probability of transitioning from the subgroup that found math difficult and boring to the subgroup of students who were curious and excited about math was 0.29, from Time 1 to Time 2. By contrast for the intent to treat group, the probability of transition from the subgroup that found math difficult and boring to the subgroup of students who were curious and excited was 0.14, from Time 1 to Time 2.

Table 3. *Prevalence of Latent Statuses and Transition Probabilities in Latent Status Membership by Actual Treated Group and Intent to Treat but Not Treated Group (N = 139 Treatment students, 150 Intent to Treat Not Treated students)*

	Latent Classes		
	Persistent and Put Extra Effort subgroup	Curious and Excited Subgroup	Find Math Difficult and Boring Subgroup
Prevalence of Latent Statuses			
Treated (Mastered >=25 lessons):			
Time 1 (Pre - Survey)	0.18	0.62	0.19
Time 2 (Post - Survey)	0.29	0.50	0.21
Intent to Treat (Mastered <25 lessons):			
Time 1 (Pre - Survey)	0.27	0.52	0.21
Time 2 (Post - Survey)	0.27	0.48	0.25
Transition from Time 1 (rows) to Time 2 (columns)			
Treated (Mastered >=25 lessons):			
Persistent and Put Extra Effort subgroup	**0.74**	0.11	0.15
Curious and Excited Subgroup	0.17	**0.69**	0.15
Find Math Difficult and Boring Subgroup	0.24	0.29	**0.47**
Intent to Treat (Mastered <25 lessons):			
Persistent and Put Extra Effort subgroup	**0.40**	0.31	0.29
Curious and Excited Subgroup	0.21	**0.70**	0.09
Find Math Difficult and Boring Subgroup	0.24	0.14	**0.62**

Note. Diagonal transition probabilities in bold to facilitate interpretation.

13. Conclusion

One of the key problems is that U.S. students are not learning the foundational math skills they need during the elementary school years. This research study evaluated the effects of an online collaborative elementary math program using team-based games to improve student math achievement, attitude and motivation. The research questions focus was on achievement, attitude and motivation. Sokikom, (pronounced so-kee-kom) is an online collaborative math program developed through grants from the Institute of Education Sciences (IES), where elementary students help each other learn through a team-based game as well as adaptive, independent learning games. Though a randomized control trial design, the researchers studied the effects of using Sokikom for 1 year in 2 elementary schools in Oxnard, CA. Specifically, effects on students' mathematics achievement as measured through the end-of-year CA state test. The results showed that there was a significant and positive association between the number of new lessons mastered and math achievement (CAASPP) scores ($p<.0001$). For each additional new lesson mastered a student's CAASPP math scores increased 0.58 points. Notably the change in mean CAASPP score. and 2) students' intrinsic motivation to learn math. End of study data showed students that used Sokikom reliably, had significantly higher Smarter Balanced math scores (18% higher) than other students, independent of teacher or school. In addition, students that used Sokikom reliably had more than twice the amount of students that significantly improved motivation and attitude toward learning mathematics compared to other students independent of teacher or school. The research study also examined that effect reliable use of Sokikom had on positively changing student math motivation and attitudes for students who find math difficult and boring and students who are curious and excited about math. The latent transition analysis(LTA) findings showed a higher probability of transitioning from the subgroup that found math difficult and boring to the subgroup that were curious and excited about math was for students who used Sokikom reliability, suggesting that Sokikom may have had a positive impact on students' math motivation. For the treated group, the probability of transitioning from the subgroup that found math difficult and boring to the subgroup of students who were curious and excited about math was 0.29, from Time 1 to Time 2. By contrast for the intent to treat group, the probability of transition from the subgroup that found math difficult and boring to the subgroup of students who were curious and excited was 0.14, from Time 1 to Time 2.

In summary this research study found that regular use of an online collaborative elementary math game program (Sokikom) by elementary students has the potential to improve math achievement and provide positive motivation in the learning of mathematics.

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