Wuzzit Trouble: The Influence of a Digital Math Game on Student Number Sense

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Abstract

This study sought to determine if playing a digital math game could increase student number sense (mathematical proficiency in numeracy). We used a pre- and post-assessment to measure the number sense of two groups of third grade students with the same mathematics teacher. One group played the game Wuzzit Trouble and the other did not. Overall, the group who played Wuzzit Trouble showed a significant increase in number sense between the pre- and post-assessment, compared to the other group who did not. A qualitative analysis of a novel problem revealed differences between the treatment and comparison groups from pre- to post-. A discussion of these findings and features of the game are addressed. Namely, two features inherent in Wuzzit Trouble are associated with the learners' increased number sense. First, Wuzzit Trouble promoted mathematical proficiency by requiring learners to attend to several mathematical constraints at once. Second, the game engaged learners in an iterative process of decision-making by calling for students to try, check, and revise their strategy as they played.

Keywords: *Mathematical proficiency, digital math games, number sense, game-based learning*

1. Introduction

Digital games are ubiquitous in the lives of students on phones, tablets, and laptops, giving educators seemingly endless choices for supporting their students' math development through digital game play. However, not all of these applications, or apps, are equally helpful. Most games instantiate a specific approach to math learning, focused on numbers and operations but ignoring mathematical proficiency. Though widespread, there is little empirical evidence about whether these games build mathematical proficiency. Mathematical proficiency involves a deep understanding of mathematical concepts, operations and relationships; flexibly and efficiently carrying out procedures; and representing, formulating, and solving mathematical problems [1]. It also includes thinking logically; reflecting and justifying ideas; and seeing mathematics as useful, worthwhile, and doable [1]. While learning procedures and basic facts is important, it is only a small part of being mathematically proficient. Yet, many of the math games available to the general public seem to be geared toward procedural and speed-related practice. A potential affordance of mobile technology is to more directly support the building of mathematical proficiency as defined above. The goal of this study was to determine if playing a mobile math game could influence the development of number sense, a particular type of mathematical proficiency.

2. Background

School mathematical experiences influence conceptions about mathematics. If one has experienced math instruction that emphasized isolated facts, procedures and memorization, then he or she tends to believe that this is the nature of mathematics, sometimes resulting in underdeveloped mathematical proficiency [2]-[4]. Game developers, like most of the American population, have experienced this type of instruction. Thus, it is not surprising that many digital math apps emphasize procedures, memorization, and speed without comprehensively attending to other aspects of mathematical proficiency. Instead of perpetuating poor math learning, digital games could promote mathematical proficiency, specifically the development of number sense [5]. Number sense involves being mathematically proficient with numbers and computations. It moves beyond the basics to developing a deep understanding about properties of numbers, and thinking flexibly about operations with numbers. In the following section, I will explain further what is meant by mathematical proficiency, the number topics related to the study, and how mathematical proficiency and number content come together to form number sense.

2.1 Defining Mathematical Proficiency

To describe successful math learning from kindergarten through 8th grade, the National Research Council [1] conducted an extensive review of research in cognitive science and mathematics education. In this report, they explain five equally important components, or strands, that make up mathematical proficiency:

- *Conceptual understanding*—understanding of mathematical concepts, operations, and relationships
- *Procedural fluency*—carrying out procedures flexibly, accurately, efficiently, and appropriately
- *Strategic competence*—ability to formulate, represent, and solve mathematical problems
- *Adaptive reasoning*—capacity for logical thought, reflection, explanation, and justification
- *Productive disposition*—seeing mathematics as sensible, useful, and worthwhile, coupled with a belief in diligence and one's own efficacy [1].

Being mathematically proficient means that one is equipped with the tools needed to meet mathematical challenges of daily life, as well as able to find success in higher level mathematics classes in high school and beyond. Mathematically proficient students have developed a deep conceptual understanding of mathematics concepts. This proficiency applies to all domains of mathematics, such as Geometry, Number and Operations, Algebra, Calculus, Probability, Measurement, and Statistics.

Devlin explains why video games are a suitable medium for developing mathematical proficiency [5]. Video games can provide a context for sustained and repeated periods of time engaging in and with mathematical concepts, solidifying procedural fluency and conceptual understanding. Students can be immersed in a world where mathematical tasks naturally arise to provide situations where strategic competence, productive disposition and adaptive reasoning can be achieved. In order for a game to support mathematical proficiency, it must be designed in a way that makes mathematics useful for navigating the virtual world.

Mathematical proficiency has been a stated priority for most mathematics educators and professional organizations. However, this emphasis has rarely translated into state standards and assessments, and consequently, into classroom practice, especially during the No Child Left Behind era's emphasis on rote learning [3], [6]-[8]. Procedural fluency is the strand of proficiency that tends to get the most attention in a typical math classroom, as well as in many digital apps, while the other strands are largely ignored. This results in an unbalanced view of mathematics, and incomplete mathematical proficiency. The strands are interdependent and should receive adequate and equal attention.

The strands of mathematical proficiency combined with the NCTM Process Standards (communication, representation, problem solving, reasoning and proof, and connections) are embodied in the Common Core State Standards for Mathematical Practices (CCSSM)[9]. The CCSSM repositions mathematical proficiency as crucial to developing mathematically competent students. This calls for a shift in the focus of math teachers, researchers, and math game developers to fostering mathematical proficiency for students at all levels of the education system. We contend that technology could play a key role in the shift.

2.2 Mathematical Content: Numbers, Operations, and the Base Ten Number System

If mathematical proficiency, as defined by the CCSSM Practices, describes *how* students should engage in learning, then the mathematical content describes *what* students should learn. Examples of math content include numbers and operations, geometry, probability, measurement, and algebra. This study focuses on content related to numbers and operations.

Numbers and Operations are a major content focus of the elementary curriculum, as emphasized by the CCSSM. This includes topics such as counting and cardinality, whole numbers, fractions, addition, subtraction, multiplication, and division. Children must be able to identify symbols that represent numerical amounts and count groups of objects. Students are expected to understand order and magnitude of numbers; place value, including the base-ten number system; and to be able to compare numbers as well as perform arithmetic operations with both whole numbers and fractions. See Appendix A for specific CCSSM Math Practices and Content Standards related to this study.

2.3 Number Content Meets Math Proficiency: Number Sense

Number sense is a critical foundation in elementary mathematics learning [1], [10], [11]. A strong background in number sense ensures success in algebra and other strands of mathematics [4], [10], [12], [13]. In this study, number sense is defined as showing mathematical proficiency with quantities and operations with number. A person who has number sense can represent number concepts with models, words and diagrams, communicate numerical ideas and problem solve in the Number domain. A person with number sense engages in the CCSSM Practices when working with numbers and related operations (Figure 1). Number sense includes flexibly composing and decomposing numbers for purposes of problem solving and computation, evaluating the reasonableness of solutions to numerical problems, and making connections between multiple solution methods [4], [14]-[16]. Furthermore, number proficient students are able to communicate their number sense verbally and in writing. They notice and explore number patterns, make connections and conjectures, and communicate their thinking to others [1], [4].

The CCSSM emphasize the development of number sense in young children. Number sense goes beyond solving word problems and memorizing basic facts and procedures [8], [14]. It involves engaging in numbers and operations in ways that develop a deep understanding of the content, which provides a firm foundation for mathematical success.

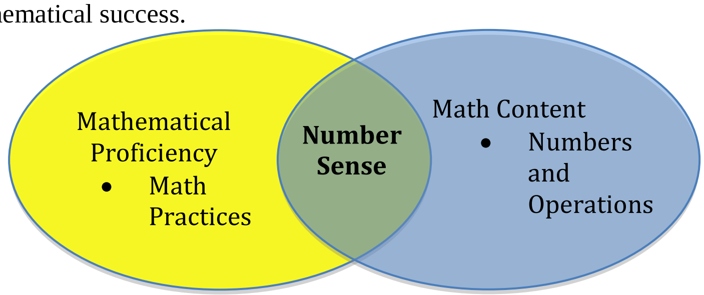

Figure 1. This figure illustrates how we think about number sense. It is the interaction of mathematical proficiency and mathematical content. Number sense can be defined as demonstrating mathematical proficiency with quantities as well as operations.

2.4 Current Research

Research showing the mathematics that is learned within digital games is emerging [17]. Three gaps in the literature exist: 1) studies using a control condition are scarce [17], 2) the learning outcomes of most of the studies focus on motivation and engagement or basic math skills rather than mathematical proficiency [18], and 3) the digital intervention games studied usually only develop procedural or memorization tasks, thus the assessments measure procedural knowledge, ignoring the other strands of mathematical proficiency [19]. For example, one recent study found that students who engaged with a mobile learning intervention outperformed students in the comparison group, but it focused on

multiplication facts measured by a speed related assessment, not the more comprehensive mathematical proficiency or number sense [20]. This study will add to the current literature because it employs a control condition and the game intervention, as well as the assessment of learning outcomes, focus on mathematical proficiency beyond procedural fluency.
We wanted to find out if students can develop number sense from playing a mobile intervention. Specifically, we aimed to answer the following questions:

- Is there a significant increase in the development of number sense for students who play a mobile digital math game, compared to students who don't?

Wuzzit Trouble is one example of a digital math game that attends to Mathematics Content and Mathematical Proficiency. Our team hypothesized that it could be an effective game for moving students beyond a superficial development of number sense.

3. Methods

3.1 The Intervention: Wuzzit Trouble

Wuzzit Trouble is a mobile math game that is available for free through iTunes App Store or Google Play (Figure 2). "Wuzzits" are colorful creatures that have been trapped in cages inside of a castle. The goal of the game is to free the Wuzzits from the cages by getting the keys. The player engages in mathematics by turning the small drive cogs, which move the larger cog in position to reach the keys (Figure 2). Click here [21] to see a video of the game in action. Wuzzit Trouble was created as an "instrument to play mathematics" [22]. For example, say the key is located at number 17 on the large cog, and you have 7 for one drive cog and 3 for the other. In order to reach the key, you would tap and turn the 7 cog two times, and tap and turn the 3 cog once to reach the key and release the Wuzzit. Many of the levels have several ways to solve them.

Figure 2. Wuzzit Trouble game interface.

The game simulates movement on a number line, constrained by the size of the jumps to get to the target numbers. The game does not rely on speed or mathematical symbols for operations (e.g., +, -, x) and can be solved in a variety of approaches. Playing Wuzzit Trouble seems to stress the conceptual intuitiveness of mathematics, which may strengthen student number sense [1]. Within the constraints of the game, the player must attend simultaneously to the size of the moves determined by the small cogs. She must also decide which direction to move the cog, and which key to pick up first. We expect that the game provides a space for productive practice that fosters successful learning of number sense. For this reason, we believe Wuzzit Trouble could promote mathematical proficiency for a wide range of players.

3.2 Participants

The participants are 59 third graders at Big Dipper Academy in the Big Tree School District of Sequoia, California[1]. Big Tree School District serves a large Latino population. Families who qualify for free and reduced lunch make up about 71% percent of the district student body. District Standardized Testing and Reporting Program (STAR) results for math show 57% of students scored proficient or advanced during the 2012-1013 academic year. Big Dipper Academy is academically, racially, and socioeconomically uncharacteristic of the larger district. White students make up 61% of the students at the school, compared to 19% of the district-wide population. According to the school's 2012-2013 School Accountability Report Card, Big Dipper Academy is high performing in mathematics, with 95% of all students proficient or advanced on the STAR tests. In order to attend Big Dipper Academy, students must take and pass an entrance exam. See Table 1 for demographics by treatment group and pre-assessment results.

Mrs. G., the third grade teacher, had previously sorted students into two classes according to perceived "ability". She also chose which class would receive the treatment, stating that the comparison group was her "high performers" and the treatment group "was having trouble memorizing their multiplication facts" (Mrs. G. electronic mail). She hoped that playing Wuzzit Trouble would help them. The students played the game on school-issued iPad tablets that the teacher reserved from the school technology department. Students played the game individually. See Table 1 for the number of students and demographics by condition.

Table 1. Student Demographics by Condition

	Comparison	**Treatment**
N	30	29
Grade	3	3
Gender		
Female, %	60 (n=18)	55 (n=16)
Race		
Nonwhite, %	63 (n=19)	38 (n=11)

3.3 Study Procedure

The teacher administered the pre-assessment to each class, with instructions to read a problem to students if they request, but to not help them solve the problems. For the treatment group, the teacher taught math as usual, minus 10 minutes allotted for individual game play in class for three times a week over a four-week period, totaling 120 minutes of game play (Table 2). The comparison group had math instruction as usual. At the end of four weeks, the teacher administered the post-assessment to both the control and intervention groups, which consisted of the same pre-assessment questions. Students in the comparison group were given access to the game after the post-assessment.

Table 2. Study Design

Comparison	**Intervention**

[1] Teacher name, school name, district, and city are pseudonyms.

*Pre-assessment	*Pre-assessment
*Math instruction as usual	*Math instruction as usual, minus 10 minutes devoted to Wuzzit Trouble play time in class, 3 times a week, totaling 120 minutes
*Post-assessment	Post-assessment

3.4 Instrument to Measure Student Outcomes: Pre- and Post-Assessment

The paper-and-pencil assessment consists of 5 brief constructed response items and was given to both the comparison and intervention groups (Appendix A). These questions were designed to mirror the number sense thinking utilized in the game, and for which typical third graders are developing understanding: addition and subtraction combinations to reach a target number, extending increasing multiplication patterns, extending decreasing multiplication patterns from a nonfactor of a number, and building two-digit numbers that represent properties of numbers, such as odd, even, and proximity to a target number. See Appendix A for the complete assessment along with the math practices and content standards each item addresses. There are 5 items, each ranging from 2 to 9 possible points. This resulted in an assessment with a possible score of 28 total points. We piloted and revised preliminary versions of the assessment to refine the items and develop a scoring rubric (Appendix B).

Upon completion, the teacher returned the pre-assessments for immediate scoring. The research team then scored 10 pre-assessments together. Any discrepancies were discussed until we came to consensus. We then scored the rest of the assessments separately. The same procedure was followed for the post-assessments. All data were entered into an Excel spreadsheet, by question and total score. We performed inter-rater reliability using the Krippendorff's alpha to determine consistency among the scorers, which was high at a=0.94. Cohen's kappa is not appropriate in this case because it used to determine the inter-rater reliability of categorical data. The pre-assessment scores are continuous data. For this reason, we used Krippendorff's alpha for continuous data [23].

3.5 Data Analysis

Using Stata statistical software, we ran a paired samples t-test by condition to determine if there was a significant difference between the change in number sense for the comparison and treatment groups.

We also completed a secondary analysis of the Question 4 (Table 3). The analysis of this item was necessary for 3 reasons; 1) as stated previously, it was the source of most of the score difference between the assessment total scores, 2) it involved elements of number sense that are not directly related to the game. This hints at transfer of learned mathematical proficiency from the game to a new situation, and 3) it is a type of problem that the students are least likely to have encountered before. In other words, Question 4 is unconventional. Table 3 shows the coding scheme used to analyze Question 4 which are based on the constraints of the problem:

- Create the <u>largest</u> even and odd number with the available digits.
- Make an <u>odd</u> number with the available digits.
- Make an <u>even</u> number with the available digits.
- Make a number as <u>close to 50</u>, not including 50, with the available digits.
- All of the numbers must be <u>2-digit</u> numbers.
- Must use each digit 0 – 9 only <u>once</u> in all of Question 4.

These became the codes for Question 4. This allowed us to uncover why Question 4 was the source of most of the difference between the treatment and comparison groups. Attending to all of these constraints in relation to properties of numbers suggests students' ability to think critically about numbers and problem solving. Students must display some number sense in order to solve it. We tallied the instances of each student's adherence to the constraints of the problem using Excel Spreadsheet.

Table 3. Codes used for detailed analysis of Q4.

Codes No=0 Yes=1	**Description of code**	***Example of student responses that scored "Yes"***			
Largest	Did the student make the largest number possible with the digits left for the even and odd numbers?	A	Largest odd	9	7
		B	Largest even	8	6
Odd	Did the student make an odd number (ending in 1, 3, 5, 7, 9) with the digits available?		Largest odd	8	5
Even	Did the student make an even number (ending in 2, 4, 6, 8, 10) with the digits available?		Largest even	7	2
Close	Did the student make a number that was as close to 50 as possible, but not 50, using the digits left?		Number closest to 50, not including 50	4	9
2-digit	Did the student make a 2-digit number (tens and ones)?		Largest odd	8	9
			Largest even	7	5
			Number closest to 50, not including 50	5	1
Once	Did the student use each digit (0-9) only once?	___	Largest odd	9	7
		___	Largest even	8	6
		___	Number closest to 50, not including 50	4	9

4. Results

We set out to investigate if playing Wuzzit Trouble increased student number sense. We will describe patterns in the total score data, then we will explain the results of the paired samples t-test (2-tailed) by condition as well as change trends in answering Question 4.

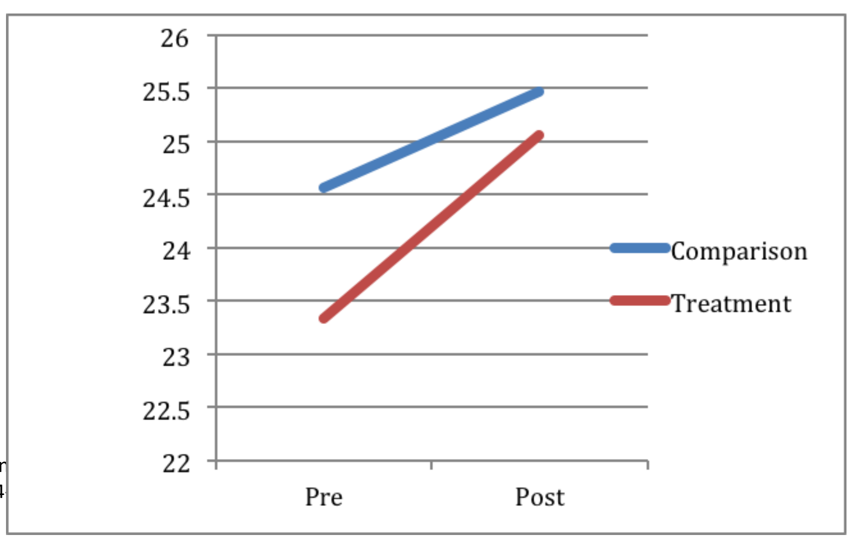

Figure 3. Change in Total Score by Condition

4.1 Mean Total Score on Pre- and Post-Assessment

As shown in Figure 3, the comparison group demonstrated a significantly higher score than the treatment group on the pre-assessment (Comparison = 24.57, s = 0.51; Treatment = 23.34, s = 0.51), t (57) = 1.6966, p < .0476). The comparison group demonstrated a slightly higher score on the post-assessment, but the difference was not significant (Comparison = 25.47, s = 1.87; Treatment = 25.07, s = 1.99), t (57) = .7894, p < .43. As displayed in Table 4, there was a significant difference in the pretests (M=23.34, SD=2.76) and posttests (M=25.07, SD=1.99) for the treatment group, at a 0.05 significance level; t (29) =3.51, p < 0.0015. In other words, the comparison and treatment groups had significantly different levels of number sense on the pre-assessment, but that difference was minimal on the post-assessment.

Table 4. Descriptive Statistics and Paired T-Test Results by Condition

Paired Samples T Test, by Condition: Pretest vs. Posttest								
	Paired Differences							
Pretest vs. Posttest	Mean Difference	Std. Dev.	Std. Error Mean	95% Confidence Interval	*t*	df	Sig. (2-tailed)	ES (Cohen's d)
Comparison	0.9	2.66975	0.48743	[-0.0969, 1.8969]	1.8464	29	0.0751	n/a
Treatment	1.72414	2.64435	0.49104	[0.7182, 2.7299]	3.5112	28	0.0015	0.92

4.2 Differences in Total Score Between Conditions

Figure 4 further illustrates this point. It shows the mean difference between the pre- and post-assessment for the comparison and treatment groups. The comparison group showed less difference between the pre- and post-assessment means (comparison difference mean= 0.90, SD=2.67). There was no significant difference in the pretests (M=24.57, SD=2.78) and posttests (M=25.47, SD=1.87) for the comparison group; t (30) =1.85, p < 0.075. The treatment group displayed a significant difference between pre- and post-assessment (treatment difference mean=1.72, SD=2.64). The effect size is high at Cohen's d = .92. This suggests that playing Wuzzit Trouble positively influences student number sense.

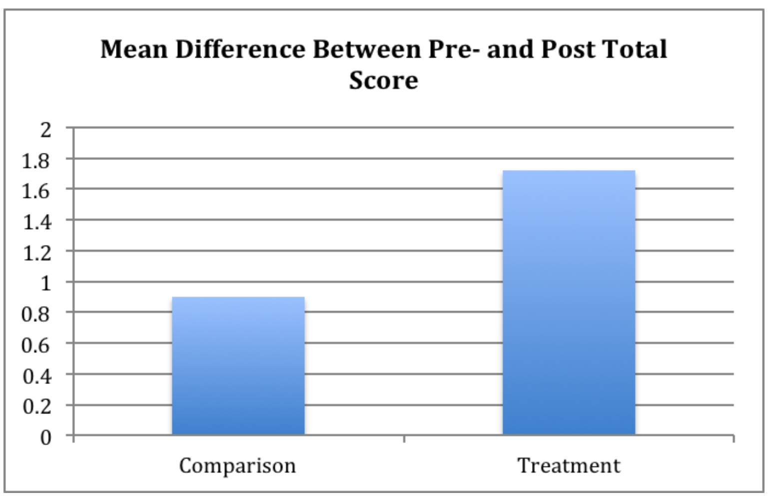

Figure 4. Mean Difference in Pre- and Post- Total Score, by Condition

4.3 Meeting Constraints of Digits Problem

Analysis of Question 4 revealed a change in students' ability to meet constraints of a novel problem. We will describe the results of the Pre-assessment, then the results of the post-assessment, followed by a comparison between the two.

Pre-Assessment_: Table 5 shows the results of Question 4 analysis. Pre-assessment percentages are similar for both the control and treatment conditions in terms of creating the largest numbers, making even numbers, and making odd numbers. Virtually all of the students can make odd and even numbers. However, less than half of the students in each group were able to make the largest number possible. The control group more consistently: 1) made a number closest to 50, 2) made 2-digit numbers, and 3) only used the digits 0 – 9 once. Students in the control condition made a number closest to 50 about 73 percent of the time, compared to the treatment condition meeting this constraint 63% of the time. Making 2-digit numbers and using each digit only once was an even more drastic difference between conditions on the pre-assessment. The "Close to 50" constraint shows a 10% difference between the control and treatment, scoring 73% and 63%, respectively. The control group made 2-digit numbers about 97% of the time, compared to the treatment group meeting this constraint around 77%. Students in the control group used each digit only once about 83% of the time, compared to the treatment group using each digit only once about 63% of the time.

Post-Assessment_: Table 5 also shows the results of Question 4 analysis on the post-assessment for each condition. More of the students in the treatment group were able to make the largest number, with 63% of them meeting that constraint, compared to only 57% of the comparison group. Again, virtually all students in both groups were able to make odd and even numbers. For both the comparison and treatment groups, about 57% of students were able to make a number close to 50. Similarly, about 90% of students in each group were able to make 2-digit numbers. More of the students in the comparison group met the constraint of using the digits once at about 83%, compared to about 77% in the treatment group. Although the comparison class had more students who were able to meet the constraints of Question 4 on the pre-assessment, the class who played Wuzzit Trouble made considerable gains on the post-assessment, catching up or surpassing the comparison class in some instances.

Table 5. Percent of Students Meeting Constraints of Digits Problem

Percent of Students Meeting Constraints on Pre- and Post-Assessments, by Condition				
	Pre-assessment		Post-assessment	
	Comparison	Treatment	Comparison	Treatment
Largest	46.67	43.33	56.67	63.33
Odd	100	93.33	96.67	93.33
Even	96.67	93.33	100	96.66
Close to 50	73.33	63.33	56.67	56.67
2-Digit	96.67	76.67	90	93.33
Used Digits Once	83.33	63.33	83.33	76.67

Figure 5 shows the change in the number of students who met the constraints of Question 4. The treatment group gained more students who were able to make the largest numbers, make 2-digit numbers, and use the digits once. While both conditions showed a decrease for "Close to 50," the treatment group decreased less than the comparison group on that particular constraint. These results suggest that playing Wuzzit Trouble positively influences some aspects of student number sense and student ability to meet constraints of an open-ended problem.

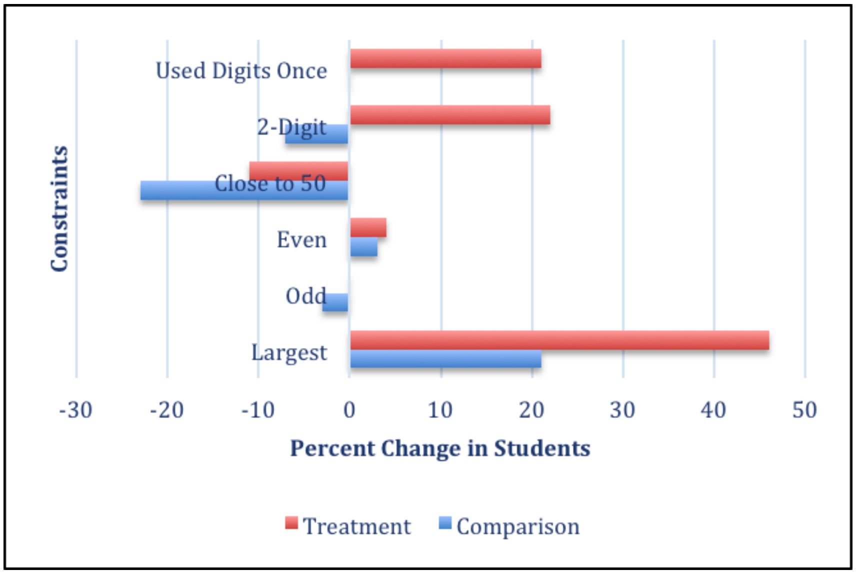

Figure 5. Change in Percent of Students Meeting Digits Constraints, by Condition

5. Discussion

This study showed that the change in total scores from pre- to post-assessment are significant for students who play the digital math game *Wuzzit Trouble*, compared to students who do not, suggesting that number sense increases for students who play the game. By examining the Question 4 qualitatively, we have also shown that students who play Wuzzit Trouble are better able to attend to constraints and apply their number sense to an unconventional problem. In this section, we examine the features of the Wuzzit Trouble game design that are similar to Question 4. Lastly, we will discuss how the game promotes productive practice and supports the successful learner in developing some aspects of number sense.

5.1 The Digits Problem, Wuzzit Trouble, and Mathematical Proficiency

There are deep structures inherent in both Wuzzit Trouble and Question 4 that promote mathematical proficiency: attending to several constraints at once, and engaging in decision-making processes. Playing the digital game helped to develop these proficiencies, which then transferred to student performance on the Digits problem.

Constraints_: As students solve levels of Wuzzit Trouble, they must attend to several constraints at once. This particular structure supports productive disposition and conceptual understanding. The player can only move the large wheel by the multiple on the driver cogs, and must reach specific numbers to get the keys and bonus items. The driver cog can be turned up to 5 times with one tap. Similarly, students must attend to constraints presented in Question 4 at the same time. The problem requires them to make the largest even 2-digit number, the largest odd 2-digit number, and the closest number to 50, all the while using digits 0-9 only once.

Decision-Making in Problem Solving_: Both Question 4 and the game call for students to try, check, and revise as they solve. This structure supports adaptive reasoning and strategic competence. The player must decide which direction to turn the cog to reach the key or keys. Then she must estimate the distance to the target number and how many turns of the drive cog or cogs to reach the target. She must also decide which combination of the drive cogs will be enough to reach the keys and bonus items. With all of these things to consider, it is not unusual for the player to carry out her decisions and find that she over-or underestimated. At this point she revises her choices by going through a similar process until she reaches the target numbers.

Question 4 also requires some level of revising decisions. There are three 2-digit numbers that the student must create using the digits 0-9: The largest odd, the largest even, and a number close to 50. First, the student must decide which one to create first, thinking about which digits would create the largest even or odd, or closest to 50. He must also keep track of which digits he's used to be sure he doesn't use them more than once. Finally, he has to check to make sure he's met each constraint, revising his answers as needed.

5.2 Productive Practice and the Successful Learner

Practice is necessary for mastery. Wuzzit Trouble provides a two-dimensional digital environment that promotes productive practice. Productive practice is meaningful repetition that moves beyond rote learning toward the development of the strands of mathematical proficiency. This environment is crucial for strong number sense.

Mathematics is about doing, as well as knowing, and a virtual math environment should reflect this [5]. The two-dimensional learning environment of Wuzzit Trouble is set up to engage the learner from the moment the game begins. With the action of tapping the smaller cogs to activate them and turning them a certain number of times to retrieve the keys, the player is using mathematics in an authentic environment to reach a goal. The player is immediately able to reflect on her choices and apply them to completing the challenge of the next level. CCSS Math Practice 1 fits well here. The player must "make sense of the problem" by analyzing the situation [9], which arises naturally as an integral part of the game [5], [6]. She must decide where the target number is, think about the given smaller cogs, and how she can use them to reach the key. This clearly develops the player's strategic competence, adaptive reasoning, and productive disposition.

Wuzzit Trouble provides an environment that motivates children to persist at playing, so they get many opportunities for meaningful practice. Furthermore, each level naturally builds on the one before it so that players can make generalizations to help them solve novel situations. Basic skills are not learned in isolation or out of context, but are discovered "bottom up" as the player progresses through the game [5], [6]. The Wuzzit Trouble platform allows each player to progress through several levels, engaging in the strands of mathematical proficiency and building number sense.

Fostering learner success in digital games requires a low-risk environment, acknowledgement of achievement, extended engagement, appropriate amount of challenge, and multiple routes to progress through the game. In many math classes and digital game environments, the focus is on the correct answer, not the process to get the correct answer. Students who are great memorizers and quick to answer tend to excel in traditional math environments. This creates an atmosphere where very few students feel comfortable taking risks for the fear of getting the wrong answer and not being seen as "smart". This fixed mindset pervades American classrooms and is communicated in ways we teach and praise math ability, and hinders student learning [11], [24]. We argue that the fixed mindset is evident in many mobile math games available to students. The two-dimensional environment of Wuzzit Trouble provides a safe zone for the player to take risks and to use mistakes as opportunities for learning, promoting a growth mindset. She is out of the spotlight and is able to focus less on appearing "smart" and more on successfully completing the game. While playing Wuzzit Trouble, the player has complete control over the cogs and is able to take risks, such as guessing, checking the guess, and making adjustments to guess and check again. This lowers the sense of failure and the player is able to protect his real-world identity.

Playing games involve some level of intrinsic rewards that fuel motivation. Wuzzit Trouble meets this principle by making the player the hero of the story. The player's goal is to rescue the Wuzzits from the traps, experiencing success from the very beginning. The player moves at her own pace through the game without competition from other students, but with an intrinsic drive to press on.

Wuzzit Trouble embodies a rich mathematical task in a digital format. It is a "low floor-high ceiling" task, meaning that people of varying mathematics backgrounds can approach the game from different starting points and still be successful with it [4], [14]-[16], [25]. Wuzzit Trouble provides opportunity for players to develop some aspects of number sense in a meaningful, engaging context. Students must reason and solve problems by conceptually thinking about composing and decomposing numbers, addition, subtraction and multiplication as they play.

6. Limitations and Next Steps

The sample size and diversity of the sample are limited. These students are at a public academy that does not represent the more diverse district in which it resides. Students must pass an entrance exam for enrollment, and 95% of students score proficient on the STAR. Therefore, generalizability is limited. Future research should include larger sample sizes and studies of learning from non-dominant cultural contexts.

Little is known about how teachers and students interacted with the game in their classrooms, or the general mathematics instruction experienced in class. Future studies should include classroom observations and teacher interviews to better understand differences in use of the game that were not captured in the current research design. This could specifically include examining the math content students are exposed to through teacher-facilitated instruction, the classroom environment, and technological pedagogical content knowledge needed by the teacher to successfully incorporate Wuzzit Trouble into curriculum and instruction. A survey of noncognitive factors that influence student learning could also shed light on student attitudes toward math and how playing the game affects dispositions.

The specific mechanisms of Wuzzit Trouble that influenced the increase in student number sense are also unclear. I speculate that the linear motion of turning the cogs give the learner a tactile experience with magnitude, factors, and multiples. However, observing students during a think-aloud task interview as they play the game will help to illuminate the attributes of the game that promote the development of number sense.

7. Conclusion

Given the increasing affordability and availability of mobile technology, it makes sense to explore using it in schools. With the type of mathematical engagement that is embedded into Wuzzit Trouble, it exemplifies a well-designed video game that could be a suitable context for learning mathematics. Educators should be aware of the types of mathematics learning a game promotes. Games that focus on speed and rote learning of skills will increase those skills in students, but may not deepen understanding. Even worse, these types of games may foster misconceptions about math being about speed and rote memory instead of the creative, flexible discipline that it is. Wuzzit Trouble is an example of a digital math game that promotes mathematical proficiency and could pave the way for a new generation of mobile math apps.

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Appendix

A. Assessment questions with related CCSS Mathematical Practices, Math Content Standards, and Strands of Mathematical Proficiency.

Assessment Item	Mathematical Proficiency as defined by CCSS Math Practices Addressed	Mathematics Content as defined by CCSS Math Content Domains and Clusters
1. Using the numbers 6 and 9, how can you make 21? Use words, pictures or numbers to show your thinking.	MP 1: *Make sense of problems and persevere in solving them.* MP2: *Reason abstractly and quantitatively*.	<u>Grade 2</u> *Domain: Operations and Algebraic Thinking* • Represent and solve problems involving addition and subtraction • Add and subtract within 20 • Work with equal groups of objects to gain foundations for multiplication
2. Finish the pattern: 6, 12, 18, 24, _______, _______, _______. How do you know what number comes next?	MP2: *Reason abstractly and quantitatively*.	<u>Grade 3</u> *Domain: Operations and Algebraic Thinking* • Represent and solve problems involving multiplication and division • Understand properties of multiplication and the relationship between multiplication and division • Multiply and divide within 100 • Solve problems involving the four operations, and identify and explain patterns in arithmetic
3. Using only 3's and 7's, use any mathematical operation to get from 45 to 28.	MP 1: *Make sense of problems and persevere in solving them.*	<u>Grade 3</u> *Domain: Operations and Algebraic Thinking* • Represent and solve problems involving multiplication and division • Understand properties of multiplication and the relationship between multiplication and division • Multiply and divide within 100 • Solve problems involving the four operations, and identify and explain patterns in arithmetic
4. You have a set of digits from 0-9. 0 1 2 3 4 5 6 7 8 9 Arrange these digits in the boxes below to make two-digit numbers as close to the targets as possible. You may use each digit only once. Tell the order in which you completed the items by marking them with A, B, or C.	MP 1: *Make sense of problems and persevere in solving them.* MP2: *Reason abstractly and quantitatively*.	*Domain: Number and Operation in Base Ten* • Use place value understanding and properties of operations to add and subtract

_______ **Largest odd** _______ **Largest even** _______ **Number closest to 50, not including 50**		
5. Finish the pattern: 55, 49, 43, 37, ___, ___, ____. How do you know what numbers come next?	MP2: *Reason abstractly and quantitatively*.	*Grade 3* *Domain: Operations and Algebraic Thinking* • Represent and solve problems involving multiplication and division • Understand properties of multiplication and the relationship between multiplication and division • Multiply and divide within 100 • Solve problems involving the four operations, and identify and explain patterns in arithmetic

Appendix B Assessment Scoring Rubric

Question 1:
2 points: Any correct numbers, words or pictures.
1 point: Any attempt
0 points: No attempt

Question 2:
a) Pattern: 30, 36, 42
4 points= continue the pattern by increasing by 6
3 point= if they start their own pattern and use it correctly
3 points=if they get the first two right
2 point= 1 correct
1point= made an attempt
0= no attempt

b) Explanation:
3points= added 6 or whatever number they used in part (a)
2 points= general statement for finding an arithmetic pattern
1point= made an attempt
0 points= Blank

Question 3:
3 points= any correct way to get from 28 to 45.
2 points= Partial engagement or not clear how they got 17
1 point= Credit for an attempt
0 points= no attempt

Question 4:
Each question graded separate (must be a 2 digit number to receive a score above 1)
Notes: A/ B can be organized together 97, 86 or 98 and 75
3 points= the largest odd
2 points= any large 2-digit odd or any 2-digit large even (6 and above in the tens place)
1 point= for another set of numbers, any attempt
0 points= No attempt

C) 3= 51 or 49, unless they have used these four digits in the first two problems.
0 points= no attempt
2 points= values within 5 of 50 (45 and above, 55 and below)
1 point= values are close to 50, but they used the digits in a previous problem

*1point=if they used the same digit twice (e.g., 88, 99)
If they provided two answers (usually 49 and 51), give them full credit for the answer that is correct.

If not indicated, we assume they went from top to bottom.

Question 5:
a) Pattern: 31, 25, 19
4 points= continue the pattern by decreasing by 6
3 point= if they start their own decreasing pattern and use it correctly
3 points=if they get the first two right
2 point= 1 correct by decreasing

2 point= any correct decreasing pattern
1 point= made an attempt
0= no attempt

b) Explanation:
3points= Subtracted 6 or whatever number they used in part (a)
2 points= general statement for finding an arithmetic pattern
1point= made an attempt
0 points= Blank

Total Score Possible: 28