White Paper

Teachley: Addimal Adventure: Bridging Research and Technology to Help Children Foster Strategy Development, Conceptual Understanding, and Number Fact Fluency

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Teachley is an educational technology company whose mission is to improve and help shape the future of teaching and learning. Founded by former teachers and experts in children's cognition and learning, Teachley uses cognitive science research to create educational apps that teach effective learning strategies and assess what kids know within engaging games. Teachley was awarded two prestigious Small Business Innovation Research grants (Phase I and II) from the Federal Department of Education to develop a suite of math apps and a student data reporting system. The project described in this paper was made possible by the Federal Department of Education, with funding provided by the Institute of Education Sciences' SBIR program.

For more information, visit us at www.teachley.com or email us at info@teachley.com

Introduction

An estimated 5 to 8% of elementary school children have "some form of memory or cognitive deficit" that inhibits the learning of basic math concepts (Geary, 2004). Dowker (2005) estimates that 6 to 20% of children have some form of math deficit, depending on the specific assessment criteria. These children are often labeled as "learning disabled," "dyslexic," and/or "dyscalculic" (Geary & Hoard, 2001). In this paper, we use the term "math learning difficulties" (MLD) to include children who struggle with mastering basic math concepts, regardless of the problem origin.

Operational fluency is a core component in early mathematics education. There are four specific areas children with MLD struggle with when learning early mathematics:

1. Number Facts. The ability to quickly and accurately perform operations on single-digit numbers (e.g. 4 + 5 or 7 x 6) is an essential component of elementary school mathematics and is the focus of significant instruction in first through fourth grade. Yet, many children with MLD have persistent difficulty in mastering these skills (Geary, 2004; Geary, Hoard, Byrd-Craven, & DeSoto, 2004; Hanich, Jordan, Kaplan, & Dick, 2001; Ostad, 1997).

2. Strategies. Children naturally use a variety of strategies to solve number facts. These strategies help children who do not yet have number facts memorized by providing them with an alternative method of solution. Students with MLD are delayed approximately two years in the development of addition strategies (Geary, Hoard, Byrd-Craven, & DeSoto, 2004). These students are less likely to see the relationship between number facts and typically fail to use the derived facts strategy. For instance, they may fail to realize that 6 + 7 is just one more than 6 + 6, or that 6 x 5 contains one more group of 5 than does 5 x 5.

3. Number sense. Students who have strong number sense (e.g. knowing that 9 + 3 is greater than 10) typically succeed in later mathematics (Jordan, Kaplan, Olah, & Locuniak, 2006). However, children with MLD consistently demonstrate weak number sense (Hanich, et al., 2001; Jordan & Hanich, 2003; Jordan, Hanich, & Kaplan, 2003a; Jordan, Hanich, & Kaplan, 2003b). The ability to determine whether an answer is reasonable and to debug errors depends on strong number sense (National Mathematics Advisory Panel, 2008).

4. Self-monitoring. In all learning, meta-level processes, such as self-monitoring and planning, are essential for growth and development. Yet, many children with MLD struggle with self-monitoring and assessing their own efficacy and understanding (Butler, 1998). In particular, they often struggle with monitoring the sequence of problem-solving steps and are unable to detect and then correct errors (Geary & Hoard, 2001; Russell & Ginsburg, 1984).

Existing Products

Applications and software designed to address number facts are widely published. Nearly all of these, however, function as digitized worksheets, virtual flash cards, or drill-based games (such as shooting the correct answer as quickly as possible). While these products encourage math fact practice, they fail to provide instruction, scaffolds, visual models, or informative feedback. While many offer claims of being research-based, these claims are often shallow and research is seldom used in meaningful ways (Sarama & Clements, 2002). Furthermore, they are not designed for children with math learning difficulties and do not foster strategy development.

Teachley: Addimal Adventure

Based on cognitive science research, *Teachley: Addimal Adventure* teaches single-digit addition to kindergarten-2nd grade students. Children practice addition facts using powerful visual models of addition strategies during the “tool round”. The “speed round” encourages memorization, but also provides hints as needed. The progress-monitoring chart allows children and parents/teachers to keep track of performance over time. Most addition apps focus on drill with digital worksheets and flashcards. In contrast, *Addimal Adventure* teaches effective math strategies and scaffolds learning to promote conceptual understanding and fact fluency.

Representations. *Addimal Adventure* uses blocks as the primary visual representation of number. Each block has a designated color based on quantity, which helps to promote a gestalt of the number (e.g. A 5-block is always red, which cues fiveness). The red 5-block stays red even after it is split into a 4-block and 1-block so that the child understands from where the 4-block and 1-block originated.

Standard early childhood math manipulatives used to teach single-digit addition typically consist of single unit blocks, such as Linker or Unifix Cubes. Teachley’s blocks differ from these traditional manipulatives in that they are continuous and do not initially show individual unit blocks. Thus, a 6-block appears as a continuous rod and does not show 6 individual units blocks, which serves to visually promote the concept of cardinality and foster more advanced strategies, such as counting on. Teachley’s blocks do transform to show individual units, however, when children need this support, for instance when children need extra practice counting by ones. This seemingly simple design is particularly important for learning outcomes as research that shows discrete units can inhibit children's use of more advanced strategies (Pagar, 2013 unpublished dissertation).

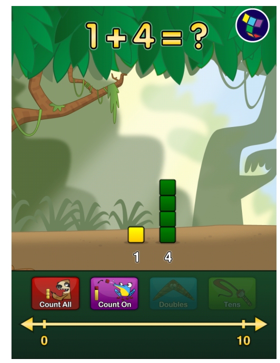
Digital blocks are also much simpler to manipulate, afford constrained movements, and are always accurate. Children can move digital blocks with a single touch on the screen rather than having to create each number as a fresh stack of cubes. While stacking Linker Cubes affords a more kinesthetic experience, digital blocks speed up the number of problems children see represented, which is especially crucial for those who may be distracted by the toy-like nature of physical cubes. Digital blocks also constrain movements to those that promote the use of appropriate strategies. For example, in solving 6 + 7 using the doubles tool, a child may cut the blocks to change the problem to 6 + 6 + 1, but they cannot change the problem to be 2 + 2 + 9 because while accurate, it is not an efficient way to use the derived facts strategy. The representation itself has rules that promote the desired mathematical thinking. Finally, the boxes are always accurate, which is not the case with Linker Cubes. Children can make mistakes with physical manipulatives that make recognizing the mathematical patterns more difficult, such as counting out 5 cubes instead of 6. Digital boxes are always correct, which in combination with the easy manipulations, ease pattern recognition.

Narrative. *Addimal Adventure* features entirely original animal characters, embedded within a

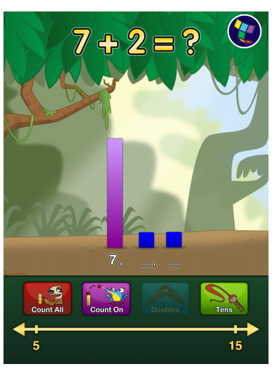
novel narrative. In *Addimal Adventure,* the evil Professor Possum has stolen all of the golden blocks from the city of El Sumado. A team of math superheroes, Captain Memo and the Addimals, help students learn addition strategies in order to win back the stolen blocks. Importantly, the characters embody the particular strategies that they model, as described below.

Tool round. The tool-round features interactive tools that model four effective strategies children use to solve addition problems.

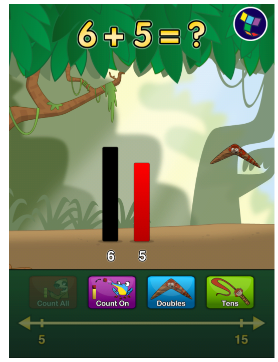
Count all tool. Counting all of the individual blocks is the first addition strategy children learn. For example, in solving 1+4, children typically count 1, 2, 3, 4, 5. Mosey, the jungle sloth, demonstrates the slow, inefficient nature of the count all strategy by turning each of the addend blocks into individual unit blocks that can then be counted. After a child demonstrates the ability to accurately count all on a regular basis, delaying or removing access to the count all tool can encourage use of other strategies, such as counting on.

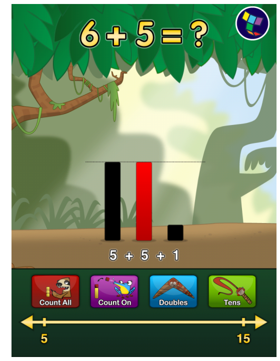


Count on tool. Children with MLD often continue to use inefficient strategies such as count all much longer than typical children (Geary, Hoard, Byrd-Craven, & DeSoto, 2004). Importantly, the count on tool scaffolds the use of the more efficient strategy by using a combination of discrete and continuous blocks. The tree frog, Patooey, models counting on by turning the continuous, smaller addend into a series of individual blocks and counting from the larger addend. For example, with 7+2, Patooey catches the 2-block with her tongue then spits out 2 individual blocks. As she counts on, the notation underneath the blocks reads, “ 7, 8, ?”. Having the first addend remain continuous aims to deter children from using the less efficient count all strategy.

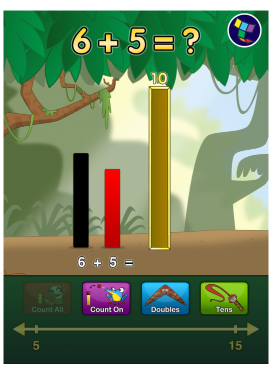


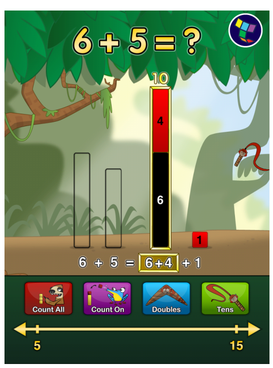
Doubles tool. *Addimal Adventure* also supports the use of derived facts, a strategy that correlates with strong number sense and often is difficult for children with MLD (Gray & Tall, 1994). By scaffolding this strategy with tools, we aim to make derived facts more accessible to all students. Doubles facts are easier for children to learn, so our first derived facts tool builds on this prior knowledge. The ninja monkey, Linka, has tools that help her decompose numbers into easier facts. Linka's doubles boomerang turns a near doubles problem such as 6 + 7 into doubles + 1 or 6 + 6 + 1.



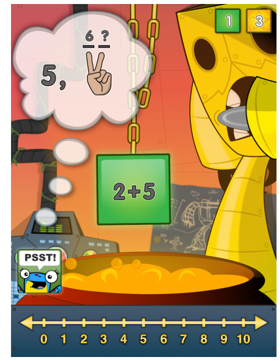


Tens tool. Combinations of ten are also important facts for children to use when solving problems with sums greater than 10. Linka has a tens-whip that pulls the addend blocks into an empty 10-frame and allowing any extra blocks to fall to the side, turning 6 + 5 into a 10-block composed of 6 and 4, as well as a 1-block outside of the ten-frame. This tool also demonstrates a non-traditional, but more accurate use of the equal sign with more than one addition problem on each side, promoting the true notion of equivalence.





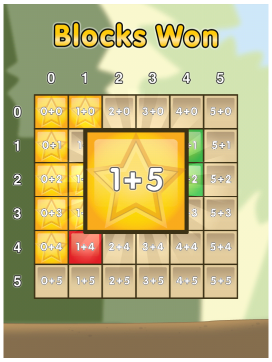
Speed Round. In *Addimal Adventure's* speed round, children visit Professor Possum's lab, where he challenges them to a memory test. The golden block with the addition fact on it is held



over a pot of molten gold by two chains. A giant robot cuts the first chain after a 2-second delay. If the child answers correctly before the chain is cut, she wins back the golden block. If the child does not answer in time or answers incorrectly, the block changes from gold to green (indicating that the fact is not memorized), and the child receives a hint from one of the characters. Each hint is designed to remind the child of a strategy he learned during the tool round or to introduce addition rules. For example, adding zero to a number results in the same number, while adding a single-digit number to ten causes it to replace the zero in 10. If the child answers correctly on the second attempt, she wins the green block, but if incorrect a second time, the block turns red and falls into the pot.

Scaffolding. In addition to improving children's awareness of strategies, *Teachley: Addimal Adventure* also uses modeling, rich scaffolding and feedback to encourage deep learning. Vygotsky's (1978) work on the Zone of Proximal Development stresses the importance of offering children modeling and support from teachers and peers at higher ability levels until the child is able to solve problems on her own. Our characters provide this type of modeling and our software gradually decreases the amount of scaffolding offered to children. For example, in the speed round, hints adjust based on the level of support needed. Typical fluency software offers little to no support for children who continue to struggle during drill exercises.

Progress-monitoring. It is important for children to be able to monitor their own progress and understanding, especially children with MLD. *Addimal Adventure* incorporates a chart that allows children and parents/teachers to track the child's progress throughout the game. The chart



is color-coded to reflect level of understanding. For example, red is used to reflect incorrect answers; green to show correct answers; and gold to indicate which facts have been memorized. The gold blocks then flip over to reveal the hidden puzzle picture of El Sumado.

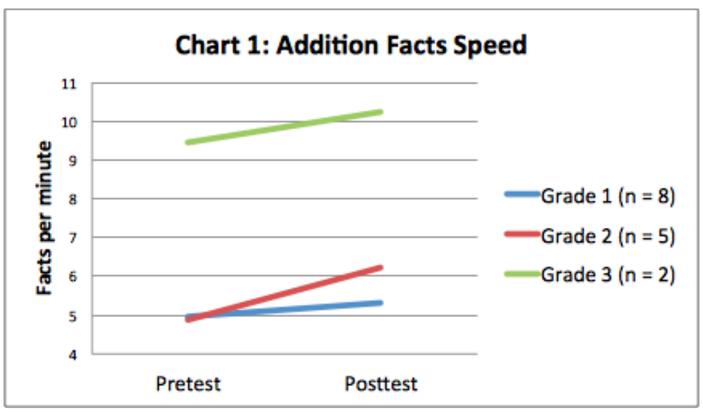
Pilot Study

A small pilot study was conducted (n=15) to determine the effects of *Addimal Adventure* on students' accuracy, speed, and strategy use. The sample included after-school students who had been identified by their teachers as needing help with addition facts. Permission forms were sent home with all identified students. 19 permission forms to participate were returned. There were more first (n = 8) and second-graders (n = 8) than third-graders (n = 3) because fewer third-graders were identified as needing help in this area. There were more girls (n= 14) than boys (n=5) in the sample, which reflected the overall population of the after-school program. Complete data are available for fifteen students due to absences and other after-school commitments.

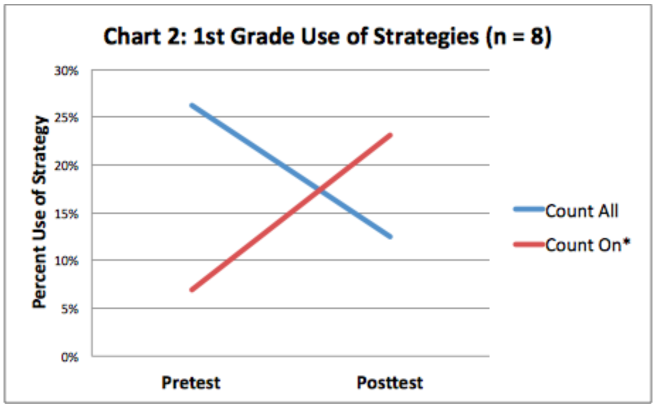
The pre/posttest measures included a commercially available addition facts assessment on the iPad called "Space Math" that tracks performance for multiple students on a flashcard-based task. The task randomly generates 20 problems with addends between 1 and 12. The app captures data about students' accuracy (% correct) and speed (time to complete all 20 questions). First-graders used the "easy" setting, which included more problems with smaller addends, while second and third-graders used the "medium" setting at both pre and posttest. In addition, we coded observed strategies for each problem.

The study consisted of five sessions: pretest, three sessions using the software, and posttest, conducted over a period of four weeks, one to two days per week. The researcher worked with children one on one in a quiet classroom or hallway.

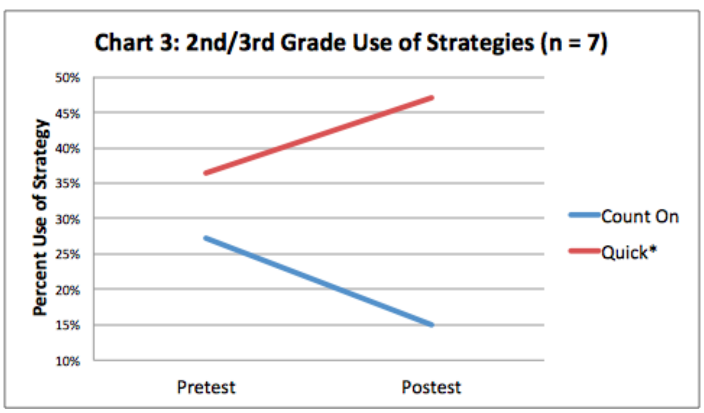
To analyze the data, a series of repeated measures ANOVAs was conducted with grade level as a factor. For these analyses, only used data from the 15 students with complete data available were included and a cutoff for statistical significance was $p = .10$, due to the small sample size. Because the addition facts assessment did not limit the amount of time students spent on each problem, the accuracy rates were quite high, mean of 87% at pretest and 91% at posttest, a non-significant difference. However the students did increase their speed significantly, taking an average of 228 seconds at pretest to answer twenty questions versus only 201 seconds at posttest ($F = 3.47$, $p = .087$). Chart 1 shows the students' increasing speed in facts per minute.



Looking more closely at strategy use reveals interesting patterns. Each student received a score for each strategy equal to the percent of trials that strategy was used (e.g. a student who used count all on 25% of the pretest trials would receive a count all score of .25 for the pretest). These scores were then used as dependent variables in a series of repeated measures ANOVAs. For first graders, counting all was a dominant strategy at pretest (26% of trials), and counting on was relatively rare (7% of trials). However, at posttest these frequencies change, with only 13% of trials using counting all and 23% counting on. Significantly more first-graders (n = 8) were counting on at posttest (F = 3.76, p = .094), whereas the reduction in counting all was non-significant (see Chart 2, significance indicated with *).



Second and third-graders did not use counting all at pretest as they had already transitioned to counting on. For these students, the goal was to abandon counting on to become more efficient in use of strategies, using derived facts or memory. Derived facts are difficult to observe because unlike counting that often utilizes fingers, use of a related fact is typically internal and unobservable. We were able to observe a trend towards less use of counting on (p = .114) and a significant increase in quick responses (F = 3.96, p = .094).



Taken together, there is initial evidence that *Addimal Adventure* is effective at improving students' fluency and strategy efficiency. The lack of control group makes it impossible to isolate these effects to the software itself. However, these initial findings suggest that Addimal

Adventure does appear to promote learning. This study will be replicated with a larger sample size within the next year to examine further the efficacy of *Addimal Adventure*.

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