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Effectiveness of Number Sense Instruction and Memorization of Math Facts

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Abstract

Math instruction is taught using a variety of methods and strategies. This literature review compares two strategies of math instruction: the instruction of number sense versus the process of memorizing math facts for students. The literature review identifies various math strategies for both number sense instruction and memorization of math facts. This literature review synthesizes studies published in scholarly journals on the topics of number sense, memorizing math facts, timed tests, math anxiety, and teacher perspectives. Studies from this review reveal that number sense instruction is beneficial for student learning to build the foundation for future mathematical knowledge before the rote memorization of math facts.

Effectiveness of Number Sense Instruction and Memorization of Math Facts

The knowledge and mastery of simple mathematic skills is a key goal in early education (Göbel, Watson, Lervåg, & Hulme, 2014) and the understanding of numbers and math operations are crucial for students of all ages (Nelson, Parker, & Zaslofsky, 2016). To lay the foundation for mastery of simple mathematic skills, researchers disagree whether children have the most success from their working memory or number sense instruction.

According to Kroesbergen and Van Dijk (2015, p. 102), working memory is the "ability to temporarily store and manipulate information." Working memory is essential in mathematics for the quick retrieval of numerical information (Kroesbergen & Van Dijk, 2015). In order to teach the strategy of quick retrieval in working memory, direct practice and timed practice along with corrective immediate feedback is used to improve fluency (Codding, Burns, & Lukito, 2011). Some strategies include the use of timed mathematic fact tests, flash cards for immediate practice, counting strategies, and individual practice (Codding et al., 2011).

On the other hand, some research shows that memorization is not the correct way to develop automatic math fact retrieval. According to Boaler (2015, p. 3), "the best way to develop fluency with numbers is to develop number sense." Gersten & Chard (1999, p. 19) refer to number sense as "a child's fluidity and flexibility with numbers". The National Mathematics Advisory Panel (NMAP) states that number sense contains the understanding of all mathematical operations, whole numbers, and place value (2008).

According to the NMAP (2008), more secondary students are lacking the ability to use numbers in a variety of ways. When students have poor number sense, it interferes with all learning of numbers and number facts for the rest of the students' education. Witzel, Ferguson, and Mink, (2012) link number sense development in young children to greater math success later in life.

The primary focus of this literature review will be to compare the effectiveness of number sense instruction in relation to memorization of math facts to improve student's fluency of mathematics. As a result of this literature review, the author will draw conclusions about whether memorizing math facts or the development of number sense for student learning is more beneficial in early childhood. This literature review also includes teachers' perceptions on which math instruction is better for student learning in the classroom, and what teachers have noticed about number sense versus memorizing math facts.

Literature Review

Number sense and working memory both play an important part of students' learning in mathematics (Kroesbergen & Van Dijk, 2015). Unfortunately, students frequently lack math fact fluency and are less likely to understand mathematical concepts for other math operations (Codding et al., 2011) due to the lack of number sense knowledge. According to the National Association of Educational Progress (NAEP) (n.d.) the math proficiency among the nation's fourth grade students in 2019 (41% of students proficient) only changed by one percent from 2017 (40% of students proficient) despite the two-year gap. In fact, the percentages for fourth grade have not change significantly in the past decade. From 2011-2019, the fourth-grade percentage report for students that remained proficient or above fluctuated between 40-42 percent (National Association for Educational Progress, n.d.) As a nation, the scores for the fourth-grade math proficiency assessment has a goal to reach 100%.

The NAEP math assessment contains questions for five domains: "number properties and operations; measurement; geometry; data analysis, statistics, and probability; and algebra" (NAEP, n.d.). While previewing the Common Core State Standards (CCSS) for math, there is a common trend between numbers and operations among all grade levels. Number sense is also included within standards for "algebra, geometry, measurement, and data analysis and probability" (Martinie & Coates, p. 88, 2007).

When teaching number properties and operations, strategies range from introducing and building number sense to the other spectrum of memorizing number properties and math facts.

Number Sense

Researchers have suggested that number sense relates closely to the cognitive thinking of the brain. Shumway and Moyer-Packenham (2019) state the cognitive philosophy of number sense is that all humans have the understanding and sense of quantity. Number sense is nonverbal, nonsymbolic, and acquired through cognitive thinking.

According to Witzel, Ferguson, & Mink (2012), children in the younger grades will succeed later in life if they are better prepared in math at an early age. Difficulties and disabilities found in young children are related to the lack of number sense and number knowledge (Witzel et al., 2012). Number sense is developed in children commonly before school-age, and "develops beyond counting to understanding the size and composition of numbers" (Martinie & Coates, p. 91, 2007). The new CCSS focus less on the memorization of math facts and more on number sense (Boaler, 2015, p. 1). Actually, number and operations are one of the five content standards for the common core. Number and operations relate closely to number sense and are found in all grade levels, from pre-kindergarten through the twelfth grade (Martinie & Coates, 2007). Number and operations build number sense knowledge and conceptual understanding over the course of the students' educational years.

There are strategies to teaching number sense for student learning. When students are given time and the opportunity to learn numbers through manipulatives, real-life problems, individual and instructional practice, and reinforcement to their learning, then students will begin to understand number sense (Godfrey & Stone, 2013). According to Wink, Ferguson, and Mink (2012), there are five different components related to number sense instruction: comparison of objects, strategic counting, word problems (including real-life word problems), basic math facts, and number-to-object recognition. When learning these components, Wink, Ferguson, and Mink (2012) suggest strategies for improving children's number sense include teaching skills for proficiency, using appropriate math language, and using concrete experiences.

Using appropriate math language when teaching number sense is often referred to as "number talks" or "math talks". Godfrey & Stone (2013) describe math talks as a separate time aside from the math lesson that engages students to focus on a particular math problem. Students are able to work through the problem together to learn from their peers and to share strategies. This time also allows teachers to model new strategies and introduce new thinking skills.

Gillard (2018) researched the effects of number talks in a third-grade classroom over the course of eight weeks. During this eight-week research, Gillard held a number talk session with third-grade students three times a week for 15 minutes. At the beginning, Gillard gave a pretest to 20 students over their knowledge of number sense. Of those 20 students, the average score on the number sense pretest was 53%. At the end of the eight weeks, Gillard gave the 20 students a

posttest that was similar to the pretest, but with different numbers. On the posttest, the 20 students received an average score of 66.3% (Gillard, 2018). Gillard also concluded that after implementing number talks within the third-grade classroom, students took less time to complete the posttest as they had gained number sense knowledge.

Another study conducted by Shumway and Moyer-Packenham (2019) included three separate classes of students to research the implementation of number talks to focus on counting involving the whole class. Overall, there were 60 seven-year-old and eight-year-old children included in this research. The three classes each included a 15-25-minute number talk session, three days a week. One class implemented number talks for 9 weeks, the second class for 6 weeks, and the third class for only 3 weeks. During each lesson, the class participated in verbal counting, writing numbers, and the use of manipulatives such as a number line. The teacher had students participate in discussion of counting sequences and number relationships, such as place value, patterns, and estimation. Students also participated and wrote in journals to reflect on the lesson for each day. There was a pretest given at the beginning of each time period and a posttest given at the end of the time period. The results showed that there was an increase in test scores for all cases, however, the longest case of 9 weeks showed the most increase (Shumway & Moyer-Packenham, 2019).

Stella and Fleming (2011) provided research on the topic of number sense instruction using different strategies. The study included 26 fifth grade students in a Title 1 school. During the study students participated in a place value math lesson

every day for twenty minutes for a six-week time period. Students participated in place value activities that included number charts (0-300), place value digit cards, place value games involving addition and subtraction, 10s and 100s blocks, and comparing and breaking apart numbers. Students participated in each activity individually and could also engage and share ideas with partners during activities. Students took a "Math Proficiency Assessment" (2011, p. 9) at the beginning of the study and as a final assessment of the study. The result from the pretest was 57.62%, while the posttest score was 61.19% overall. The research concluded that the use of the various place value activities and number sense strategies improved the students' scores (Stella & Fleming, 2011).

Aside from number talks, there are various number sense activities that may be implemented into daily instruction to improve number sense. Chen, Li, & Yang (2013) conducted a study to two separate third-grade classes (17 students in each class), both for a time period of one semester. One class received strictly number sense-based instruction, taught by a teacher who had previously taken a course on how to teach number sense-based instruction. The other class received strictly textbook-based instruction, also taught by a teacher who had taken a course on how to teach textbook-based curriculum. Within the number-sense based class, the teacher implemented various number sense activities such as small and whole class discussions, student led conversations to support their thinking, and providing feedback from student peers to engage in a deeper understanding of number sense. The teacher conducted a total of 20 number sense instructional activities in about 7 weeks. The textbook-based instruction class included more "drills and practice"

(Chen et al., p.7, 2013). The teacher for the textbook-based class also included 20 activities from the third-grade curriculum textbook. Researchers conducted a pretest and posttest for each class. The number sense-based class mean was 57.41 (out of 100) on the pretest. For the posttest, the mean score was 78.35 (out of 100); nearly a 21-point increase. As for the textbook-based class instruction, the pretest mean score was 59.29 and the posttest score was 63.06; merely a rough 4-point increase. The conclusion was made that the number sense-based class showed significant progress when compared with the class that received textbook-based instruction (Chen et al., 2013).

Studies have shown that number sense instruction has been beneficial for student learning. Number sense builds the foundation for further mathematic learning and knowledge starting early in elementary.

Working Memory of Math Facts

Working memory has been found to be essential for math performance for storing and processing numerical information (Kroesbergen & Van Dijk, 2015). Nelson et al., (2016) stated that basic math computation is a fundamental skill that is necessary to build skills for future development. There are strategies for improving students' working memory to recall math facts that include timed tests, direct practice, immediate feedback, flash cards, and individual practice.

Timed tests for mathematics can be given in all grade levels for different time periods to test for different levels of understanding. Some students believe that memorizing math facts for timed tests is the most important part of their math learning. These students do not get true number sense knowledge, and instead

memorize their math facts to score efficiently on timed tests (Boaler, 2014). Timed test scores may not be a good indicator of future math proficiency. Some research suggests when students take timed tests, their working memory becomes blocked and students start to develop anxiety and stress (Boaler, 2014). Research has been shown that math anxiety can develop as early as five-years-old (Boaler, 2015). Jordan (2007) observed a first-grade student who struggled with counting and relied on his fingers as a strategy to solve addition and subtraction problems. By fourth grade, this student had developed an increase in math anxiety and became frustrated easily with math problems because he could not pass timed math tests. By middle school, the student had developed a negative outlook for the subject of math.

Young, Wu, and Menon (2012) conducted research with 46 students in second and third grade to determine if math anxiety develops when answering math problems. There were multiple neurological assessments that students were a part of including the Wechsler Abbreviated Scale of Intelligence, the Wechsler Individual Achievement Test, the Working Memory Test Battery for Children, as well as a MRI for both addition and subtraction assessments (Young et al., 2012). The study concluded that students with anxiety had an increase in brain activity in the areas of that were associated with fear. Students with high math anxiety showed slower responses in areas with math, number reasoning and recognition, problem solving as well as attention and memory.

McGee, Richardson, Brewer, Gonulates, Hodgson, & Weinel (2017) conducted a study that included all students in third, fourth, and fifth grades in three

elementary schools (in the same district) for a total of nearly 700 students. The study focused on two specific research questions: whether automaticity drills (timed tests) for math increases standardized test scores, and whether a relationship exists between automaticity and conceptual understanding. All three schools had teachers equally trained and used the same math curriculum. Two of the three schools only provided math facts for students to practice and made it completely voluntary to learn the math facts using automaticity. The other school followed the same math curriculum and teaching, but it additionally required 10 minutes of explicit, direct math fact instruction every day. The school district participated in this research study for five months. The students were assessed by taking a district automaticity test, Kentucky Performance Rating for Educational Progress (KPREP), and a pretest and posttest for the Iowa Test of Basic Skills (ITBS) that were conducted a year apart. Looking at the overall results, the school that initiated the 10-minute mandate of required math fact instruction showed the lowest growth rate between pretests and posttests compared to the other two schools with voluntary automaticity of math facts. Researchers stated that there was no relationship to show that automaticity drills could positively increase math computation scores. It was also noted in the study that conceptual understanding was not linked with the automaticity drills; however, over a long period of time the conceptual understanding may be built upon with the repeated instruction of numbers and operations.

Boso (2011) conducted an action research study with 19 first-grade students, from January through July. Boso was using and continued to use flashcards and

timed tests as a way to learn basic math facts for the first half of the year. During the time of the study, Boso implemented six various number sense strategies that included numbers "adding zero and one, adding two, doubles (facts), doubles plus one, sums to ten, and adding nine" (2011, p. 13). Students took a math fact pretest and posttest and kept student journals. Boso also used parent feedback evaluations to determine if timed tests and flashcards were more effective for student learning, or if students preferred the six new strategies that were taught. Students used only flashcards and timed tests for six weeks then took the math test. For the subsequent six weeks, Boso taught one strategy a week using manipulatives, student journals, and number lines. Students completed the same math test at the end of the study. The results from the two math tests showed that 17 out of 19 students had increased or maintained their math scores while learning the new math strategies compared to the use of flash cards and timed tests. Boso also timed the sections of the tests that were broken down into the six new strategies. After students learned the six new strategies, the results showed that the time it took students to answer the questions in each section was faster than the pretest at the end of the first six weeks. Boso also asked parents for feedback about their child and which math strategy (flash cards and timed tests vs. new math strategies) they found to be most effective. When answering the question about the new math strategies, 7 out of 10 families stated they thought the new math strategies were more beneficial. Parents also stated they've seen a positive change of attitude in their child regarding math facts since learning the new strategies. As a result of this action research, Boso determined that the use of the new strategies was highly effective and will continue

to use the strategies to teach math facts while using timed tests and flashcards as a supplemental activity (Boso, 2011).

Although working memory is an important part of math development, the use of memorizing math facts through timed tests, flash cards, and other strategies have shown to increase anxiety in students and does not show an increase in overall math computation or standardized test scores.

Teacher Perceptions of Number Sense vs. Math Fact Fluency

Although the CCSS sets the standards and domains for each subject and grade level, it is the teacher's responsibility to teach the content and choose engagement strategies to increase student learning. When teaching math, there are numerous strategies that teachers employ to teach math lessons including flashcards, individual practice, games, number talk strategies, and paper/pencil work in addition of math curriculum (Shields, 2011). Teachers select strategies and approaches they believe to be most valuable, including the use of number sense instruction and math fact fluency.

Shields (2011) researched how teachers feel about the value of math instruction including math facts and automaticity. A total of 10 teachers that taught first, second, and third grade participated in the study. Shields first asked feedback from the teachers on the value they placed on the automaticity of math facts. Six of the ten teachers believed it was important. One of the four teachers who thought that automaticity was not important said students are not ready for that skill. The second research question asked how much time teachers allotted for students to practice math facts. Three of the ten teachers reported not allotting time for

practicing math facts at all, because it was not included in their math curriculum. The rest of the teachers reported they scheduled 15-30 minutes a week for practicing math facts because they saw value in it aside from not being included in the curriculum. Of the responses to Shield's research questions, there was a common theme of stress when it came to the students. Eight out of the ten teachers reported that math fact memorization "of speed is stressful and unrealistic" (2011, p. 56). Teachers also mentioned they felt as if they were trying to get students caught up from previous years of not knowing their facts, which would cause stress for themselves. When it came down to conceptual understanding of numbers, two teachers "stated that a child must fully understand the underlying concept before attempting to memorize the facts" (2011, p. 59).

During the action research study done by Boso (2011), teacher interviews were conducted to determine what teachers use for math fact instruction. Three of the four teachers involved in the interview stated they use timed tests and flashcards to teach math facts. All teachers reported to using different strategies for different learners, but one teacher specifically stated that number sense strategies help her students learn more than the rote memorization of math facts. Only one teacher said that he encourages memorization of math facts. Overall, the teachers agreed that when students are using strategies effectively, they enjoy it, but if they struggle with the strategy then they become frustrated when solving math facts (Boso, 2011).

Conversely, Lohse (2018) studied teachers' perspectives of the importance of number sense in early childhood. Lohse interviewed three preschool teachers about

number sense methods and their beliefs about number sense. All participants stated that number sense begins before school-age. Parental experience, home life, math language, and life experiences are all included in number sense building. In their classrooms, the participants stated they introduced new number sense topics when the student showed interest and was ready. All three teachers mentioned the use of manipulatives in order to teach number sense for counting and number knowledge such as games, songs, number lines, board games, counters, dice, etc.

Overall, teachers are using strategies they believe to be most successful for their students. The research synthesized in this literature review represented strategies for both number sense and math fact instruction in classrooms. The overall consensus of the teachers in this literature review is not sufficient to draw a conclusion about which type of math instruction—number sense or memorizing math facts—teachers perceive is more successful. Further research needs to be done to include a much more significant number of teachers. It would also be helpful to discern whether teachers' perceptions are based on their personal experience using only one method, or on an understanding of published research.

Conclusion

The results of this literature review identified the impact of number sense instruction compared to the memorization of math facts and how they impact student learning. Included in this research were positive studies that reported an increase of student mathematical knowledge when students participated in various number sense strategies like number talks, peer interactions, problem solving, exploring manipulatives, and engaging in real-life experiences. This literature

review also reviewed the effects of memorizing math facts through the use of timed tests, flash cards, and independent practice. However, further research is needed on the use of flash cards and independent practice in order to determine the impacts on student learning.

In the literature review, memorization of math facts was shown to have a negative impact on student learning and resulted in increased math anxiety. The use of memorizing math facts did not result in a positive correlation for standardized math assessments or math computation assessments.

Also included in this literature review were teacher perceptions on math strategies they believe are most beneficial for student learning. Teachers reported to using a variety of different strategies in order to teach number sense and memorize math facts for their students. Teachers described seeing increased math anxiety in students when engaged in memorizing math fact activities. However, further research needs to be conducted to find sufficient evidence on which type of math instruction is more successful for student learning.

The percentage of fourth grade students in the nation who scored proficient in math is alarmingly low and has remained flatlined within the past decade. When previewing the math standards for the nation, number sense is a common area of focus for all grade levels. A growing body of research suggests number sense instruction results in improved student outcomes in math and may be superior to traditional strategies requiring rote memorization.

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