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# DEVELOPING NUMBER SENSE IN STUDENTS WITH MATHEMATICS LEARNING DISABILITY RISK

Mehmet Hayri SARI
Assoc.Prof.Dr., Nevşehir Hacı Bektaş Veli University,
Faculty of Education, Basic Education Department, Nevşehir, Turkey
ORCID: https://orcid.org/0000-0002-7159-2635
mhsari@nevsehir.edu.tr

Sinan OLKUN
Prof.Dr., Final International University, Kyrenia, North Cyprus
ORCID: https://orcid.org/ 0000-0003-3764-2528
sinan.olkun@final.edu.tr

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**Abstract**

Learning or doing mathematics involves approximate quantification. The purpose of this research was to improve approximate number system acuity in primary school students with low achievement in mathematics. A quasi-experimental, pre-test, post-test design with a control group was utilized. Mathematics Achievement Test (MAT), Arithmetic Performance Test (APT), Number Line Estimation Test (NLE), and Raven Standard Progressive Matrices Test (RSPMT) have been conducted to identify the study groups. Initially, 302 students were surveyed with these tests. A total of 26 students scoring the lowest (bottom 25%) in all these tests, except RSPMT, have been included in the study. Students were randomly assigned to the experimental (13 students) and control groups (13 students). Experimental group played with Tablet-PC games designed to develop approximate number system, one of the components of number sense, in their free times in school. Control group, did not have any of these games but played nonmathematical games. Experimental group played with three games designed to develop number sense for two hours a week for a total of 6 hours. Analysis showed there was an increase in both of the estimation precision and mathematics achievement of the experimental group. The games played during the experimental process not only helped in teaching the spatial representation of magnitude but they also led to an improved mathematics achievement. The approximate number system sensitivity of experimental group continued to develop in retention period as measured by the 0-100 number line test. Despite an indication that number line estimation tasks have an impact on number sense and mathematics achievement, none of these results provided any evidence on being reflected on timed arithmetic performance. Activities targeting exact number system may be required for arithmetic performance. This hypothesis can be tested in future studies.

**Keywords:** Approximate number system, mathematics achievement, low achievers, number games, number sense

## INTRODUCTION

At the initial stages, learning or doing mathematics can be considered to be a quantification process. Quantities could be either discrete like 3 marbles, or continuous like length. While we enumerate the discrete quantities through subitizing and counting, we quantify the continuous quantities via measurement. In addition, we estimate and calculate the amount of both types of quantities. Consider the following situations to exemplify these actions in real life. Why is it that an infant who is unable to count but still try to reach to the plate with more cookies in it, or for a hungry lion to attack a buffalo herd with fewer buffalos rather than more buffalos in it, or similarly, for a monkey to reach to bananas that have been hung closer to it within the same cage. The first thing that strikes the mind is basic mathematical skills. More specifically, this is being expressed as something closely related to some kind of number perception or the ability to perceive quantity, which is commonly called as the number sense (Dehaene, 2001). It has been claimed that number sense is inherent in humans and some animal species and that it can be improved with experience (Feigenson, Dehaene & Spelke, 2004; Lipton & Spelke, 2003; Xue & Spelke, 2000). So, coming naturally –through genetic transfer- and developing with experience, how is number sense defined?

**What is number sense?**

Number sense has been defined in a number of different ways by psychologists and math education researchers. Dehaene (2001) defines it as the ability to rapidly comprehend quantities, determine their approximate size and perform fluent operations with them. Reys, Reys, McIntosh, Emanuelsson, Johansson & Yang (1999), on the other hand, defined number sense as the ability to have a general conception of numbers and operations; being able to make flexible mathematical assessments and the ability and tendency to use this conception to develop useful and effective strategies to manage quantitative circumstances. Similarly, number sense is defined as the ability to comprehend the meanings of numbers, to develop multiple relations between numbers, to know related quantities and to operate with numbers (National Council of Teachers of Mathematics [NCTM], 1989). Even though each one of these definitions provide different perspectives regarding number sense, the basic characteristics of number sense, in general, cover using different numeric representations, knowing relative and absolute sizes of numbers, selecting and using reference points, separating and re-arranging numbers, grasping the associated effects of the operations on numbers and making flexible and correct mental calculations and estimations (Reys & Yang, 1998).

**Components of number sense**

Based on studies conducted on babies, adults and animals, it could be safe to claim that animal creatures' (including human) cognition has a different core systems for the representation of numbers and that the number component, or the core systems of number found in it consists of two sub-systems called approximate number system (ANS) and exact number system (ENS) (Feigenson et al., 2004; Spelke & Kinzler, 2007). It is also claimed that in addition to the one found in animals, humans have an additional sub-system, which is used to make a connection with quantity and its representations with symbols (Rousselle & Noel, 2007). Thanks to this system one can learn advanced mathematics (Butterworth, 2005). With that in mind, the current study is addressing the basic components of the core number system, which is deemed to be inherent in humans.

With regards to these components, while exact number system (ENS) is emphasizing the importance of expressing exact values of numbers (mostly quantities smaller than 5), approximate number system (ANS) is more about determining the approximate values of quantities (Izard, Pica, Spelke & Dehaene, 2008; Olkun, Altun, Göçer Şahin, & Akkurt-Denizli, 2015a). Access to Symbol System (ATS), on the other hand, is the function of accessing the magnitude through symbols or symbols through magnitudes (Rousselle & Noel, 2007).

Some researchers' claim that individual differences observed in school mathematics achievement is due to the sensitivity of ANS (Mazzocco, Feigenson & Halberda, 2011; Hellgren, Halberda, Forsman, Aden & Libertus, 2013). They further claimed that the most probable reason behind dyscalculia is the deficiency in ANS sensitivity (Mazzocco et al., 2011; Libertus, Feigenson & Halberda, 2011). Some other researchers however believe that dyscalculia is due to the deficiency of ENS (Landerl, Bevan & Butterworth, 2004). In contrast to these hypotheses, it is also claimed that dyscalculia is not caused by ANS and or ENS but it is rather caused by the inability to establish a connection between quantity and its symbolic representation, or in other words, by the deficiency of accessing size through symbols or accessing symbols through size (Rousselle & Noel, 2007; Girelli, Lucangeli & Butterworth, 2000).

**The relation between the components of number sense and mathematics achievement**

A number of studies have been conducted to reveal the relation between the three sub-systems (ENS, ANS, ATS) of number sense components and mathematics achievement (Izard et al., 2008, Siegler & Booth; 2005; Starr, Libertus & Brannon, 2013). One or more of the three systems of number sense are believed to be the reason behind the failure of individuals in mathematics, or in other words, the difficulties they face when learning mathematics. There are a number of counter-findings related to the impact of the performance of these three sub-systems on mathematics achievement. While some advocate a strong relation between approximate number system's (ANS) sensitivity and mathematics achievement (Starr et al., 2013; Wilson & Dehaene, 2007; Halberda, Mazzacco & Feigenson, 2008; Libertus et al., 2011; Olkun, Sarı & Smith, 2019; Sarı & Olkun, 2018; Olkun, Mutlu & Sarı, 2017), some others believe it is actually the exact number system (ENS) sensitivity which determines mathematics achievement (Landerl, Bevan & Butterworth, 2004; Butterworth & Laurillard, 2010). There are also others who believe in a connection between high performances in access to symbol system (ATS) and mathematics achievement (Rousselle & Noel, 2007; Rubinsten & Henik, 2005). Hence, core deficit, containing all or some of ANS, ENS and ATS could be the reason behind mathematics achievement or mathematics failure of individuals (Butterworth, 2010; Olkun et al., 2015).

Starr et al. (2013) sees ANS sensitivity as an important predictor of mathematics achievement and quantitative knowledge. Furthermore, ANS sensitivity is seen as the basis for future mathematics achievement. Symbolic arithmetic is claimed to have been constructed on more primitive, approximate quantitative representations. There are also some evidences that show spatial skills are equally important for visualising a number or a quantity, or shortly, for visual representation (Olkun & Sarı, 2016). Similarly, Wilson & Dehaene (2007) deem ANS as the basic system of quantitative knowledge and arithmetic ability and believe any disorder in ANS will lead to disorders in both symbolic and non-symbolic quantitative operations. Therefore, children with ANS disorders can experience difficulties in deciding which digit is greater in a two-digit number, making predictions on a visual number line, and making calculations etc. (Wilson & Dehaene, 2007).

**Developing the components of number sense**

The ever-growing importance of mathematical skills in reaching academic and professional success in the modern world is a fact. When teaching mathematics, the highly complicated processes of the domain-specific cognitive development must be taken into consideration. Almost every child is unique in developing numerical skills. In particular, the fact that individuals with difficulties in learning mathematics lag two-years behind their peers (Shalev, 2004) led researchers to provide additional learning opportunities that aim to support them to catch with their peers by increasing their potential to learn in regular classes.

Early detection of dyscalculic students and the effectiveness of the education provided to such students are deemed to be an opportunity to lead them out of failure (Olkun, 2012). Because brain plasticity is at a very high level during early ages (Zamarian, Ischebeck, & Delazer, 2009). In other words, brain is more flexible during the younger years in terms of learning, renewing and improving abilities, hence intervention programs are being developed for younger children (See Whyte & Bull, 2008; Griffin, Case & Siegler, 1994; Käser, Baschera, Kohn, Kucian, Richtmann, Grond, Gross, & von-Aster, 2013; Wilson, Revkin, Cohen, Cohen, & Dehaene, 2006).

Dyscalculics are experiencing problems with such quantitative competencies as counting, magnitude comparison, arithmetic, number words, spatial representations of numeric quantities (Kucian & von-Aster, 2015). Previous studies paid particular importance to developing basic quantitative skills such as writing the numbers, comparing quantities, ordering numbers in terms of their sizes. In this sense, the fact that traditional interventions are not fully effective on students with a poor number sense, led researchers and educators towards different educational intervention techniques (Shalev, Manor & Gross-Tsur, 2005). More recently however, attention has been given to such basic skills as guessing the position of a given number on a number line. This is because these skills form the basis of number sense and is the building blocks for complicated skills, hence becoming a predictor for future mathematics achievement (Whyte & Bull, 2008).

A review of literature indicates that priority is given to intervention programs supporting approximate number system (ANS) and exact number system (ENS) within the core deficit hypothesis for students with dyscalculia. Development of ANS is prioritized more due to the theory claiming younger children with mathematical difficulty have insufficient estimation skills (Siegler & Booth, 2004; Booth & Siegler, 2006; Whyte & Bull, 2008; Kucian et al., 2011), as the mental number line estimation accuracy of children are believed to be associated with other basic quantitative/arithmetic competencies and mathematics achievement. Experiences related to the development of children's knowledge on quantity are said to be effective on their future learning of arithmetic and other mathematical skills (Laski & Siegler, 2014; Moeller, Fischer, Nuerk & Cress, 2015; Olkun et al., 2015a; Siegler & Ramani, 2009). Therefore, researchers have developed simple board games and computer games, assisting ANS, and applied to pre-school children and primary school students with a poor number sense. Previous works held on developing the number sense are summarized in Table 1 in the Appendix.

Activities related to developing number sense are based on two different approaches (Table 1). One of these approaches is simple board games. Aiming to develop number sense, the board games have been designed on the basis of the household game Chutes and Ladders (Figure 1). Chutes and Ladders is a game that consists of numbers starting from zero and increasing consecutively until 100.

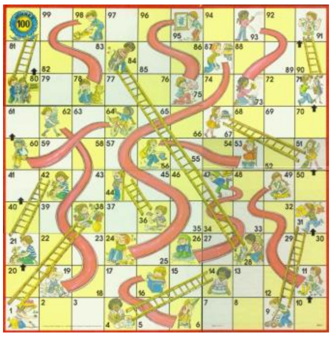

**Figure 1.** Chutes and Ladders


**Figure 2.** Number board

As seen on Figure 2, authors of these games have placed the board games in a square like hundred table. They claim that since the numbers are placed in order and in equal intervals, such board games are supposedly helping linear lines or imaginary number lines to be perceived physically (Siegler & Booth, 2004; Siegler & Ramani, 2008). As reported by Siegler and Booth (2004), board games provide various clues regarding the order and size of numbers. When a child moves the token in the game, the greater number the token reaches (a) the distance travelled by the token, (b) the number of each moves by child, (c) the amount of numbers heard and spoken by the child and (d) the time passed while moving are increasing proportionally. However, contrary to the number line, number 1 in these board games is visually closer to number 11 when compared to the distance between number 10 and number 11, therefore it may not be possible to establish a direct number-size relation. The distance travelled and the time passed might be related to the size of the numbers but the distance between the static numbers or relative locations of numbers, as in 1 and 11, do not seem to be conveying the relative sizes of numbers.

Previous studies confirm that consecutive board games help to develop a child's perception of numbers, even if they do not provide him/her through a real linear approach. These studies have also proven that it is possible to train and develop spatial representation of quantities both in typically developing children and in those with a developmental dyscalculia (Siegler & Ramani, 2008; Siegler & Ramani, 2009; Ramani & Siegler, 2008; Wythe & Bull, 2008). In addition to developing the accuracy of mental number line, simple consecutive board games are also observed to assist other quantitative abilities such as counting skills, naming numbers and comparing numbers which are not taught directly in these games (Ramani & Siegler, 2008; Laski & Siegler, 2014). However, their effect on mathematics achievement in a broader sense is unclear.

The second approach in studies held to develop number sense is the use of digital technology in cognitive training. An attempt has been made by researchers to use technology-assisted education to develop number sense by taking into consideration the positive effects of board games on the quantitative development and mathematics achievement of children (See Fischer et al., 2011; Fischer et al., 2015; Kucian et al., 2011; Käser et al., 2013; Kiili et al., 2015; Link et al., 2013; Link et al., 2014; Wilson et al., 2006). Moreover, researchers utilized digital technologies, particularly due to the possibility of designing in accordance with every child's skill and the opportunity to provide intense education within a stimulant environment (Kullik, 2004). Furthermore, the use of technology in education is yielding significant results in both behavioural and neural terms and this created new paths for researchers (Moeller et al., 2015). For instance; providing technologic assistance in learning environments can help to create learning environments that conform to children's cognitive or performance profiles. Technology can create motivation and enhance positive identity perception by helping each student to gain a sense of achievement (Käser et al., 2013).

In summary, findings related to both board games and technology-based games developed to improve number sense indicate that an education program related to the spatial representations of numbers not only enhances the ability to correctly position numbers on an imaginary number line but it also develops other quantitative competencies (comparison of size, arithmetic operations etc.). It has been further shown that a well-designed mathematics learning game, even in a short period of time, can lead to significant leaps forward in mathematical competency and such leaps can be transferred into other fields of mathematics (Kiili et al., 2015).

In conclusion, the findings of previous studies are indicating that the design of unique learning environments aiming to develop number sense through educational interventions are promising. Even though the educational interventions provide researchers with an idea about the development of number sense, a number of limitations in these studies are making it difficult to generalize these studies to a wider scale. For example, it has been reported that in many studies aiming to develop number sense, retention is not measured (Käser et al., 2013; Wythe & Bull, 2008; Wilson et al., 2006). Most of the studies are conducted on a very small sample group (N≤10) (Käser et al., 2013; Kiili et al., 2015; Wythe & Bull, 2008; Wilson et al., 2006), and the target mass of most games are preschool children. Programs designed for preschool children are mostly concentrating on constructing basic quantitative skills. However, programs designed for primary school children need to be targeting a wider skill range (counting, arithmetic, estimation, spatial perception etc.) (Käser et al., 2013). It has been particularly observed that the training programs are not tested with regards to their reflections on arithmetic achievement and mathematics achievement.

The purpose of this current study is to investigate the effects of technology-assisted educational games, designed to develop number sense of fourth graders, on developing the number sense of students and the effects on their mathematics achievement and arithmetic performances. Ethical permission has been granted by NHBV University Ethical Committee with its 2nd meeting on February 5, 2018.

## METHODS

### Research Design

This study has been designed as a quasi-experimental design with a pre-test―post-test control group (Büyüköztürk, 2014). Quasi-experimental models are preferred when the controls required by real-experimental models cannot be met or are insufficient (Karasar, 2012, p.99). In this design, participants are tried to be matched from self-forming groups (Büyüköztürk, Çakmak, Akgün, Karadeniz & Demirel, 2009, p.206). In this sense, this current study has used quasi-experimental design, as there was no way of randomly assigning the participants into experimental and control groups. Despite being a strong research model, the pre-test―post-test control design does at the same time contain some weaknesses such as the risk of sensitivity mitigation of subjects as measurement tools are administered twice to the groups. Therefore, it is suggested to perform a retention test after a while completing the experimental intervention (Heppner, Kivlighan & Wampold, 1999). In this sense, three weeks after the end of the trail, a retention test has been conducted to see whether the impact of the program is still on.

**Study Group**

The study group consists of 4th graders selected from two different public primary schools located in mid socio-economic areas in Nevşehir province. Group matching method has been employed for determining the study group of the research. This method works by defining groups that are equal and/or close in terms of the averages of relevant variables (cited in Büyüköztürk, 2014 from Eckhardt & Ermann, 2014, p. 22). In order to conduct such a group matching, 4th grade students from different primary schools have been administered "Mathematics Achievement Test", "Arithmetic Performance Test", "Number Line Test" and Raven SPM test. In each school, students scoring the lowest 25% from all these tests, excluding the Raven SPMT, have been included in the study. Students performing in the bottom %15 in Raven SPMT were also excluded from the study. The mean and standard deviations of the scores obtained by the groups through the measuring tools applied as pre-test are shown in Table 2.

**Table 2.** Descriptive statistics of the pre-tests

| Placement Test | Groups | N | Mean | Std.Dev. |
|---|---|---|---|---|
| Mathematics Achievement Test | Experimental | 13 | 6.00 | 1.78 |
| | Control | 13 | 5.54 | 2.40 |
| Arithmetic Performance Test | Experimental | 13 | 66.00 | 11.40 |
| | Control | 13 | 65.15 | 12.63 |
| Number Line Test, NLE-10 | Experimental | 13 | 26.61 | 9.48 |
| | Control | 13 | 34.21 | 18.43 |
| Number Line Test, NLE-100 | Experimental | 13 | 432.71 | 142.21 |
| | Control | 13 | 439.11 | 103.17 |

**Data Collection Tools**

During the data collection phase, participants included in the experimental and control groups have been administered to mathematics achievement test, arithmetic performance test and number line test as pre-test, post-test and retention tests. Furthermore, RAVEN Standard Progressive Matrices test has been conducted to see whether the students in study group have at least certain intellectual level.

*Mathematics achievement test (MAT)* has been developed by Fidan (2013) for primary school 4th graders based on the number domain of the Turkish Mathematics Curriculum (Ministry of National Education, 2015). It contains such subtopics as counting numbers, number patterns, arithmetic operations and fractions among others. The KR-20 reliability coefficient of the test was calculated as .96, while the reliability coefficient of the current test has been calculated as .91. The duration of the test is one class hour. This test has been used in this study both to determine the sample groups, and to measure the effect of the specifically designed games on the mathematics achievement of the students.

*Arithmetic performance test (APT),* has been developed by De Vos (1992) and adopted into Turkish by Olkun, Can and Yeşilpınar (2013) and it consists of arithmetic operations (addition, subtraction, multiplication and division). It has a total of 200 questions, with 40 questions in each column. First column contains addition, 2nd column subtraction, 3rd column multiplication, 4th column division, and 5th column mixed operations. Olkun, Can and Yeşilpınar (2013), found the KR-20 reliability coefficient as .95 under time constraint. KR-20 coefficient has been calculated as .94 in this study. Each column is distributed separately to the students during the testing and the recommended duration for each column is 1 minute. This test is also used for determining the sample groups, to measure the effect of the specifically designed games on the arithmetic performances of the students.

*Number Line Estimation Test (NLE)* includes the task of estimating the position of a given number on a number line. Developed by Olkun and Sarı (2016), the content has been expanded as part of this study. Prepared as a computer-based program, "Number Line Estimation Test" is using number lines between the ranges of 0-10 and 0-100. Students performed two exercises, one for both ranges, before starting the actual test.

*Raven Standard Progressive Matrices (Raven SPM)* Test is measuring analytic thinking, problem solving, sequential thinking and the speed of abstraction and mental activity. In addition to general aptitude, the test is evaluating visual-spatial perception, judgement, mental flexibility, abstract thinking and analytic thinking, or fluid intelligence in other words (quoted by Başbay, 2008 from Kiriş & Karakaş, 2004). Raven SPM test is believed to measure analytic, regular and correct thinking ability, mental skill and activity speed independent from academic achievement or verbal ability (cited by Başbay, 2008 from Karakaş, 2004). Raven SPM test consists of 5 sets (A, B, C, D, E) and there are 12 questions in each set. A figure with a missing part is given in each set and students are asked to use one of the 5 options to complete the figure. The suggested duration for the test is 50 minutes. The test-retest reliability coefficient of Raven SPMT changes on the basis of time interval, sample size and age groups and the current test-retest reliability has been observed to be within the range of .55 and .93 (Khalek 1988; cited by Kurt, Bekçi & Karakaş, 2004). The purpose of having Raven SPM test in this study is to exclude the bottom 15% with the worst performance from the distribution of the scores to be obtained in this test. The reason for excluding this slice of students is that these students are most likely below-average mental capacity (Raven, Raven & Court, 2000).

**Learning-Teaching Process**

The experimental group played with three different games oriented to develop number sense in children. The games have been developed by the researchers based on similar traditional games. The names of the games are Adventures with Numbers: Archery, Adventures with Numbers: Treasure, and Adventures with Numbers: Slingshot. These games are meant to develop approximate number system (ANS) in children, as it is important for mathematical cognition. These games have been developed to ensure a development in spatial representation of numbers. They are being played on number lines with ranges of 0-10 and 0-100.

Feedback has been received from the colleagues to see whether the games reflect the aspects of ANS, and also to see if there are any limitations or deficiencies in the games. Feedback has been provided by field experts, through e-mail or face-to-face interviews. Experts from the fields of mathematics education and computer-education technologies have been consulted to receive their opinions about the conformity of the designed games. Details of these games are given below:

*Adventures with Numbers: Archery*

The scenario is based on shooting arrows. By touching and pushing it to the sides, the direction of the arrow changes. A target board appears where the direction meets the number line. When the child thinks the direction is pointing the correct position of the number, the arrow is shot to mark the target number on the number line (See, Figure 3 and 4).

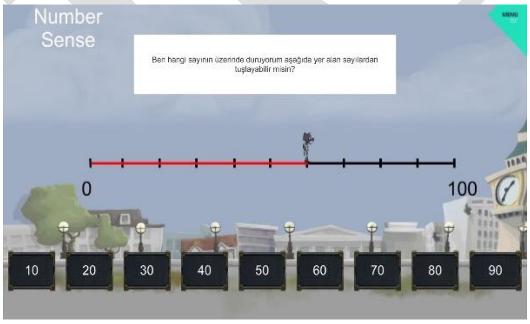


**Figure 3.** Practice with archery

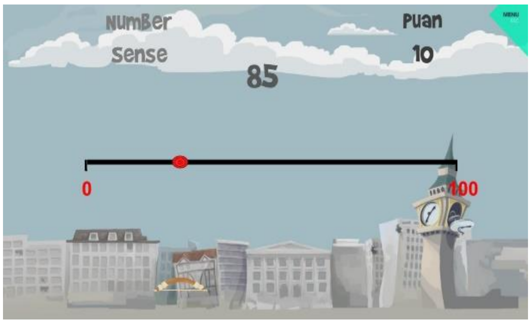


**Figure 4.** Actual game with archery

*Adventures with Numbers: Slingshot*

The scenario is shooting rubbles with a slingshot. The player is supposed to shoot the rubble on a target of his choice on the number line. After identifying the possible location of the number asked on

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the screen the slingshot is pulled and released and a red flag appears on the hit target (See, Figure 5 and 6).


**Figure 5.** Practice with slingshot

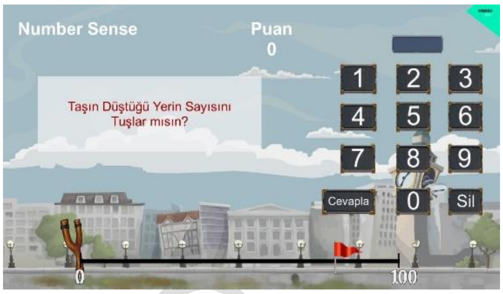


**Figure 6.** Actual game with slingshot

*Adventures with Numbers: Treasure*

The scenario is based on getting the gold placed inside the treasure chest. The game involves the child estimating the approximate value of the treasure chest’s location on the number line to earn the gold inside it. The treasure chest hangs on the number line and the child estimates the approximate position of the chest to get the gold (See, Figure 7 and 8).

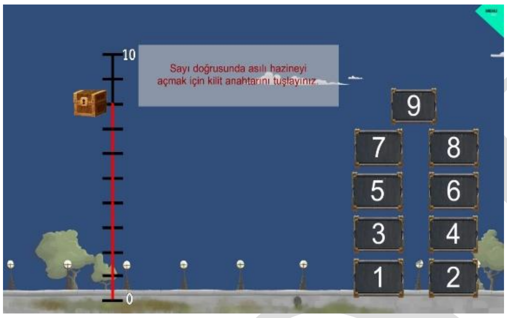


**Figure 7.** Practice with treasure


**Figure 8.** Actual game with treasure

All the above explained games have been played by the subjects on a tablet-PC in a dedicated classroom. A tablet-PC has been distributed to groups of two students and the three games were played by the students for two hours a week and a total of 6 hours. Post-tests have been conducted following the completion of the six-hour practise with games. Then a three-week break was given before conducting a retention test to observe retention. Meanwhile the control group students continued with their normal education in their classroom.

**Data Analysis**

Before deciding on which analysis technique is to be used, data have been reviewed to see if they meet normality assumptions such as Skewness and Kurtosis. Data of independent variables indicate that Skewness and Kurtosis values are lower than the accepted threshold of 1.96 (Can, 2014). It has been decided that data were distributed normally and parametric statistical analysis methods could be used.

In order to interpret the scores obtained from the “Mathematics Achievement Test” “Arithmetic Performance Test” and “Number Line Estimation Test” during the pre-test, post-test and retention test stages of the experimental design of the study, an independent sample test, independent t-test has been conducted (Büyüköztürk, 2010; Can, 2014). The total absolute error (TAE) scores were calculated for the NLE-10 and NLE-100 tests by using the formula “Estimations – to be estimated number)/scale” as suggested by Siegler and Booth (2004).

 

## RESULTS

Pre-test scores of the experimental and control groups have been tested through an independent samples t-test analysis to see if their scores are similar in terms of number sense (NLE-10 and NLE-100), mathematics achievement, and arithmetic performance. The results of the analysis are given in Table 3.

**Table 3.** Comparisons of pre-test scores of experimental and control groups

| Test | Groups | N | Mean | Std.Dev. | t | p* |
|---|---|---|---|---|---|---|
| NLE-10 Pre-test | Experimental | 13 | 26.61 | 9.48 | 1.322 | .203 |
| | Control | 13 | 34.21 | 18.43 | | |
| NLE-100 Pre-test | Experimental | 13 | 432.71 | 142.21 | .131 | .897 |
| | Control | 13 | 439.11 | 103.17 | | |
| MAT Pre-test | Experimental | 13 | 6.00 | 1.78 | .557 | .583 |
| | Control | 13 | 5.54 | 2.40 | | |
| APT Pre-test | Experimental | 13 | 66.00 | 11.40 | .179 | .859 |
| | Control | 13 | 65.15 | 12.63 | | |

*p<.05

Results indicated that the experimental and control groups involved in the study did not differ significantly in their number line estimations as measured by their total absolute errors in 0-10 interval number line [$t_{(24)}$=1.322, p>.05], and in 0-100 interval number line [$t_{(24)}$=.131, p>.05]. They were also not significantly different from each other in mathematics achievement scores [$t_{(24)}$=.557, p>.05], and arithmetic performance scores [$t_{(24)}$=.179, p>.05]. In other words, it could be said that prior to the experimental intervention, the achievement levels of groups were very close to each other.

We conducted independent samples t-test analysis to see if there are any differences between post-tests of the experimental and control groups number sense measurements where the experimental group played games designed to develop number sense while the control group had no such experience. The results are given in Table 4.

**Table 4.** Comparisons of experimental and control groups' number senses

| Test | Groups | N | Mean | Std.Dev. | t | p |
|---|---|---|---|---|---|---|
| NLE-10 post test | Experimental | 13 | 8.08 | 3.34 | 2.637 | .014* |
| | Control | 13 | 21.76 | 18.41 | | |
| NLE-100 post test | Experimental | 13 | 183.03 | 46.37 | 3.124 | .005** |
| | Control | 13 | 272.80 | 92.67 | | |

*p<.05; **p<.01

As seen in Table 4, it has been observed that there were significant differences between estimation scores as measured by total absolute errors both in 0-10 interval number line [$t_{(24)}$=2.637, p<.05] and in 0-100 interval number line [$t_{(24)}$=3.124, p<.01]. This observed difference between averages of the groups is in favour of the experimental group. In other words, it can be said that Tablet-PC applications used by the experimental group to develop number sense led to an improvement for the number line estimation skills of students in the experimental group. It can also be said that through the games the number line estimation skills of the experimental group students become more accurate when compared to control group students.

We conducted independent samples t-test analysis, to see if there were any differences between the mathematics achievement and arithmetic performances of experimental and control groups after the intervention. As presented in Table 5, a significant difference has been observed between the experimental and control groups mathematics achievement scores [$t_{(24)}$=3.098, p<.005]. This observed difference is in favour of the experimental group. In other words, Tablet-PC applications used by the experimental group to develop number sense led to an improvement in mathematics achievements of the students.

**Table 5.** Comparisons of experimental and control groups' mathematics achievement and arithmetic performances on post-tests

| Test | Groups | N | Mean | Std.Dev. | t | p |
|---|---|---|---|---|---|---|
| MAT Post-test | Experiment | 13 | 13.00 | 2.04 | 3.098 | .005* |
| | Control | 13 | 9.00 | 4.18 | | |
| APT Post-test | Experiment | 13 | 80.92 | 14.71 | .663 | .514 |
| | Control | 13 | 76.76 | 17.14 | | |

*p<.01

A comparison of arithmetic performances of the groups involved in the study (Table 5) has not indicated any significant difference between the post-test scores of experimental and control groups [$t_{(24)}$=.663, p>.05]. In other words, the games designed to develop number sense did not have any additional effect on the arithmetic performances of the students in the experimental group. In fact, both experimental and control groups' scores improved nearly equally. Arithmetic performance is more about Exact Number System (ENS). This study however, has only targeted approximate number system (ANS). So, this is an expected result.

**Retention tests**

Looking at the results of the retention test score averages (Table 6), held three weeks after the completion of the experimental intervention, there were significant differences among total absolute errors in number line estimations of both in 0-10 interval number line [$t_{(24)}$=2.274, p<.04] and in 0-100 interval number line [$t_{(24)}$=2.867, p<.012]. These observed differences are in favour of the experimental group.

**Table 6.** Comparisons of number line estimations of experimental and control groups

| Test | Groups | N | Mean | Std.Dev. | t | p |
|---|---|---|---|---|---|---|
| NLE-10 | Experimental | 13 | 8.06 | 3.46 | 2.274 | .040* |
| Retention | Control | 13 | 16.34 | 12.66 | | |
| NLE-100 | Experimental | 13 | 164.67 | 34.54 | 2.867 | .012* |
| Retention | Control | 13 | 242.04 | 90.96 | | |

*p<.05

Table 7 indicates a significant difference between the experimental and control groups in terms of mathematics achievement retention test held three weeks after the experiment [$t_{(24)}$=2.274, p<.05] but no such difference has been observed again between the groups in terms of arithmetic performance [$t_{(24)}$=1.287, p>.05]. The observed difference in mathematics achievement in favour of experimental group in post-test has continued in the retention test. Similarly, there was no difference between the experimental and control groups in terms of arithmetic performance in the post-tests and the same applies to the retention test.

**Table 7.** Comparisons of mathematics achievement and arithmetic performance of experimental and control groups

| Test | Groups | N | Mean | Std.Dev. | t | p |
|---|---|---|---|---|---|---|
| MAT | Experiment | 13 | 12.77 | 1.96 | 2.774 | .012* |
| Retention | Control | 13 | 9.54 | 3.71 | | |
| APT | Experiment | 13 | 81.85 | 12.18 | 1.287 | .210 |
| Retention | Control | 13 | 73.92 | 18.55 | | |

*p<.05

## DISCUSSION and CONCLUSIONS

Educational interventions that conform to new approaches targeting individuals with number sense insufficiency or mathematics difficulty are still on a developmental stage. Early detection of individuals with number sense insufficiency or mathematics difficulty and developing suitable intervention programs for them is important for the development of mathematical skills of these individuals. Previous studies on number sense or mathematics difficulties in primary school do provide us with some ideas, however the effect of developing different components (approximate number system, exact number system, access to symbol system) of "number sense" on mathematics achievement has not been fully studied. Such studies are only being brought recently to the field of mathematics education. Studies held in Turkey, for instance, are mostly on identifying individuals with a lack of number sense and revealing the relation between number sense and mathematics achievement (Olkun, 2012; Olkun et al., 2015a; Olkun & Akkurt-Denizli, 2015b; Yaman, 2014). There is only one study conducted in Turkey with the purpose of developing number sense through educational-experimental intervention (See Olkun & Özdem, 2015c). It targets subitizing and arithmetic facts components of the exact number system.

The current research is investigating the number sense development of fourth graders with low mathematics achievement through technology-assisted games. It also aimed at investigating the effect of number sense games on mathematics achievement and arithmetic performance. Furthermore, retention tests have been conducted to obtain findings related to the reflections of the games on number sense development, mathematics achievement, and arithmetic performance.

The education activities held in the experimental group through tablet PC games led to a significant improvement in the number line estimation skills of students with low achievement in mathematics and a decrease in total absolute errors in their number line estimations. This finding is an indication that it is possible to train and develop the spatial representation of numbers. The greater improvement in the number sense of the experimental group students compared to control group students conform to the findings in literature. Spatial accuracy of number line estimations has been observed to develop in education activities aiming to develop quantity representation both in dyscalculic and in normal developing children (Siegler & Ramani, 2009; Whyte & Bull, 2008; Wilson, Revkin, Cohen, Cohen & Dehaene, 2006; Käser, Baschera, Kohn, Kucian, Richtmann, Grond, Gross & von-Aster, 2013; Kucian, Grond, Rotzer, Henzi, Schönmann, Plangger, Gälli, Martin & von Aster, 2011; Fischer, Moeller, Bientzle, Cress & Nuerk, 2011).

Further to teaching spatial representation of numerical magnitudes, the games played during the experiment also contributed to a development in mathematics achievement. A significant increase has been observed in the numeric performances of experimental group students with lower mathematics achievement. This significant finding is an indication that it is possible to increase mathematics achievement of a child by developing approximate number system, which is an important dimension of inherent number sense. Previous studies have also provided evidence regarding the existence of the relation between approximate number system sensitivity and mathematics achievement (Kucian et al., 2011; Kucian et al., 2013; Griffin et al., 1994; Link et al., 2013).

Kucian et al., (2011) reported that education programs provided for developing the quantity representation in dyscalculic children have a positive effect on the mathematical achievement of these children. Ramani and Siegler (2008) on the other hand, concluded that playing with simple linear board games not only develop spatial accuracy of mental number line but it also has a positive impact on other quantitative tests such as counting skills, naming numbers and number comparison, which cannot be taught directly during the linear board games. It has been reported that a well-designed mathematics learning game, even in a short period of time, can lead to significant leaps forward in mathematical competency and such leaps can be transferred into other fields of mathematics (Kiili et al., 2015). The findings of the current study provided additional evidence to the improvability of mathematics achievement through number sense training.

Another significant finding of the current study is the fact that tablet-PC games designed in accordance with the approximate number system did not yield a meaningful difference between the arithmetic performances of experimental group students. Despite an increase in the arithmetic performances within the groups, no significant difference has been observed among the experimental and control groups. There are evidences in the literature indicating that the approximate number system and exact number systems of individuals with counting and calculation difficulties are not working properly (Landerl, Bevan & Butterworth, 2004). There is an ongoing debate about arithmetic operations, in the sense that whether they are performed with exact number system or approximate number system. But there are evidences that both systems are being used (Cohen & Dehaene, 2000). For instance, students who internalized the rules of numbers and are operating with any two numbers, provide a single answer as it should be (such as 6+5=11) while students with difficulties in calculation can provide multiple answers (such as 6+5=10 or 12). This is an indication that along with exact number system, approximate number system is also involved. Over time, it is possible to give the correct answer off by heart as a result of internalizing.

Findings related to retention indicate that the success achieved in post-test total absolute errors in number line (0-10 and 0-100) estimations has continued in retention test. Specifically, total absolute error of experimental group students receded from 183.03 to 164.67 in the post-test. That means students in the experimental group improved their approximate number system relatively permanently. Something similar has also been observed in mathematics achievement test retention scores. The difference between the experimental and control group students, as obtained in the post-test, has been observed in the retention test too. In terms of arithmetic performances, no differences were observed in the post-test and in retention test between the experimental and control group students. Despite indicating that quantity representation activities have an impact on number sense and mathematics achievement, no evidence has been produced on any impact on arithmetic performance.

ANS sensitivity is deemed to be the predictor behind future mathematics achievement and symbolic arithmetic is deemed to be constructed on more primitive quantitative representations (Starr, Libertus & Brannon, 2013). Although we did not find any evidence of arithmetic improvement in this study, Wilson, Revkin, Cohen, Cohen & Dehaene, (2006) reported a significant increase in the basic number sense performances of children, and the ratio of correct answers in subtraction exercises had a reported average increase of 23%. There was no improvement observed throughout the study with regards to the performances in addition exercises and in base-ten conception exercises. In previous studies Olkun, Mutlu and Sarı (2017) found that the number line estimation skills of students within the 0-100 interval account for 5% of the variance in arithmetic performance. In the same study, Weber fraction and NLE 10 (small numbers) contributed more to arithmetic performance as measured by Arithmetic Performance Test (APT) than mathematics achievement as measured by MAT. On the other hand, NLE 100 (large numbers) contributed more to mathematics achievement than arithmetic performance (Olkun et al., 2017).

## Suggestions

In summary, estimation acuity, a component of number sense, is related to the future mathematics achievement (Berch, 2005) but may not be that directly related to arithmetic performance, which depends mostly on exact number system. With regards to arithmetic performance, activities targeting exact number system may be necessary. This hypothesis can be tested in future studies.

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## Appendices **

**Table 1.** A summary of the actions taken to improve components of number sense

| Program name | Researchers | Age group | Education duration | Content | Research Limitations |
|---|---|---|---|---|---|
| *Paper-pen and board games* | | | | | |
| Number Board Games | Siegler & Ramani, 2009 | 4-5 | 3 weeks and 15-20 minutes a day | Approximate Number System (ANS) and Exact Number System | Retention not tested |

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| | | | | | |
|---|---|---|---|---|---|
| | | | | (ENS) | |
| Number Board Games | Whyte & Bull, 2008 | 3-4 | 4 sessions and 25 minutes in each session | ANS | Retention not tested and there is no control group |
| Number Board Games | Siegler & Ramani, 2008 | 4-5 | 2 weeks and 15 minutes | ANS | There is no control group, retention not tested |
| Number Board Games | Ramani & Siegler, 2008 | 4-5 | 2 weeks and 15-20 minutes | ANS | There is no control group |
| Number Board Games | Laski & Siegler, 2014 | 6 | 3 weeks and two class hours a week | ANS | Retention not tested and there is no control group, sampling group not sufficient |
| Disorganized Point Counting Game | Authors, 2015 | 8-9 | 2 days and 1 hour a day | ENS | Retention not tested |
| *Technology assisted educational games* | | | | | |
| Number Race | Wilson, Revkin, Cohen, Cohen & Dehaene, 2006 | 7-9 | 5 weeks and half an hour a day | ANS and ENS | Studied a small-sized group (n=9), retention not tested and there is no control group. |
| Calcularis | Käser, Baschera, Kohn, Kucian, Richtmann, Grond, Gross & von-Aster, 2013 | 8-11 | 6-12 weeks and 20 minutes a day | ANS and ENS | Retention not tested, dyscalculic students not identified through a standard test and there is no control group. |
| Rescue Calcularis | Kucian, Grond, Rotzer, Henzi, Schönmann, Plangger, Gälli, Martin, & von Aster, 2011 | 8-10 | 5 weeks and 15 minutes a day | ANS and ENS | Groups have different intellectual levels, retention not tested in control group, sample group is limited |
| Digital Dance mat Training | Fischer, Moeller, Bientzle, Cress & Nuerk, 2011 | 5-6 | 3 weeks and 15 minutes a day | ANS | Tool used in education is not common, |
| Kinect training | Link, Moeller, Huber, Fischer & Nuerk, 2013 | 7 | 3 class hours | ANS | Mechanism occupies a lot of space, there is a need for a longer term activity |
| Digital Dance mat Training | Link, Schwarz, Huber, Fischer, Nuerk, Cress & Moeller, 2014 | 8 | - | ANS | - |
| Full-body Movement | Fischer, Moeller, Huber, Cress & Nuerk, 2015 | 7-8 | 15 minutes | ANS | Lack of time, trial and control groups unevenly distributed, sample group size is small |
| Semideus | Kiili, Devlin, Perttula, Tuomi & Lindstedt, 2015 | 12-13 | 2 months and 40 minutes a week | ANS | Retention not tested, Sample size is small, group equality lacking, duration not sufficient |