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# Monitoring proficiency: Growth of number sense in primary school

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## Abstract

The purpose of this study is to develop tests for monitoring the number sense skills of primary school students based on proficiency definitions and to compare their number sense skills according to gender, school type, and mother's educational level. The first stage addressed to test development in which anchor items were used for vertical equating of number sense tests across grade levels. In the second stage, the number sense skills were compared in terms of student characteristics. The participants were 2034 primary school students. Reliable and valid number sense tests each consisting of 20 items were developed that allow comparison among Grades 2, 3, and 4. The findings indicated that number sense skills were not developed sufficiently in early childhood and had different trends in terms of gender through grades. Moreover, private schools outperformed public schools and the gap became higher in Grade 4. The results also showed that mother's education is an important factor for children to have higher number sense skills. Number sense is a prominent predictor of mathematics performance and monitoring number sense progress helps to evaluate the effectiveness of mathematics instruction.

## Practitioner points

- Number sense is an essential component of mathematical understanding.

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- The developed tests provide monitoring number sense skills.
- Common items in the tests across grades allow vertical articulation.

**KEYWORDS**
bookmark method, differential item functioning, number sense, proficiency definition, test development

## 1 | INTRODUCTION

The number sense, defined as how children comprehend numbers, quantities, and how they relate to one another, computational fluency, make estimations and do arrangements, plays a key role in improving mathematical skills (Dehaene, 1997, 2001). Aside from such properties, some researchers have taken the definition of number sense further and described it as trying different ways to make mathematical inferences about numbers and operations and developing different strategies to cope with numbers and operations (McIntosh et al., 1992). The number sense was defined as a main objective of mathematics instruction (NCTM, 2000; National Research Council [NRC], 2001). Understanding and discriminating the magnitude of numbers and quantity (Clements & Sarama, 2007; Jordan et al., 2007), ordering numbers (Clements & Sarama, 2007; NCTM, 2000), recognizing numbers (Jordan et al., 2007), and comprehending the quantities of numbers (Clements & Sarama, 2007; NCTM, 2000) refer to number sense-related skills. According to Reys et al. (1999), students with number sense exhibit skills such as comparing the quantities and estimated results, finding alternative ways based on arithmetic operations, and judging the appropriateness of the achieved results. Additionally, number sense is also important for developing an understanding of basic arithmetic operations as counting is the essence of learning. National Council of Teachers of Mathematics (NCTM, 2000) states that understanding of numbers and operations is extremely necessary to comprehend the concepts of geometry, measurement, algebra, data analysis, and probability both in primary school and the future educational levels.

Foundations of number sense skills that are closely related to mathematics achievement are laid even before children start school (Jordan et al., 2010). This important concept is the most important predictor of mathematical performance in years to come (Friso-van den Bos et al., 2014). Improvement of number sense starts with the absolute representations of small numbers whereas large quantities are understood through approximate representations at the beginning. These representations are the foundations of symbolic or verbal number proficiencies (Feigenson et al., 2004). When children have learned the verbal counting and understood the cardinality of numbers, they learn how to completely represent greater numbers and see that each number is idiosyncratic (Le Corre & Carey, 2007; Sarnecka & Carey, 2008). Children first adapt to number words in the small sets, for example, three or smaller (Le Corre & Carey, 2007). Then, most children learn how to count individually by one-to-one matching of numbers in a fixed order and comprehend that the last number refers to the number of all elements in the set (Gelman & Gallistel, 1978). Comprehending the principle of counting enables children to enumerate any object in any direction (e.g., from left to right or right to left). Counting skill significantly affects numerical understanding (Baroody, 1987), makes it easier for children to understand that quantities of subsequent numbers in the count list are greater than the previous ones (Sarnecka & Carey, 2008) and enables them to add up or subtract on the set by using or not using an object (Levine et al., 1992). A child whose number sense has developed can utilize the concept of number line to develop a basic mathematical understanding and develop next skills such as addition and subtraction. For instance, comprehending that four is greater than two is based on the

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information that numbers always follow a certain order and subsequent number is always greater. Given all these considerations, there is a consensus on the necessity of number sense for school mathematics.

The learning difficulties in mathematics result from the lack of number sense skills (Gersten et al., 2005; Mazzocco & Thompson, 2005). Basic deficiencies in number sense (estimation, number line, counting operations, etc.) affect all activities, including quantities and the operation process (Butterworth, 2010), and constitute the reason for low mathematics achievement (Kuhn & Holling, 2014). Indeed, number sense skills include counting, using counting words to define quantities, comparing numbers with quantities, and learning the appropriate use of numbers during operations. During all these phases, formal and informal knowledge develop (Friso-van den Bos et al., 2014).

## 2 | THEORETICAL FRAMEWORK

Many studies have focused on the components of number sense (Greeno, 1991; McIntosh et al., 1992; NCTM, 2000; Resnick, 1989; Reys et al., 1999; Yang, 1995). NCTM (2000) listed the components as (a) comprehending the numbers, ways of representing the numbers, and relationships among numbers; (b) understanding the meaning of operations and how they relate to one another; and (c) computing fluently and making meaningful estimations. These components include the skills of understanding the meaning of numbers and operations (e.g., knowing that there would be many different decimals between 0.27 and 0.28; McIntosh et al., 1992; Yang & Sianturi, 2019a, 2019b), making meaning of number systems such as integers, fractions, decimals, place value, basic arithmetical operations; ranking and comparing the numbers flexibly (e.g., when comparing 4/5 and 3/7, comprehending that 4/5 is greater than 1/2 and 3/7 is smaller than 1/2; Yang & Sianturi, 2021), using different notations of numbers and operations; comprehending how basic arithmetical operations will affect the calculation (e.g., understanding that multiplication will not always result in a greater number), performing mental operations and using estimation strategies (e.g., when performing the operation $938.5 \times 0.496 = ?$ with the choices of (a) 46.5496, (b) 465.496, (c) 4654.96, (d) not applicable, thinking that 465.496 is the answer because $900 \times 0.496$ [which is approximately 1/2] results in approximately 450; Yang & Sianturi, 2021) (McIntosh et al.,1992; Yang & Sianturi, 2021). Similar to these structures, Aunio and Räsänen (2016) define a model consisting of core numerical skills developmentally based on four factors: (1) symbolic and nonsymbolic number sense, (2) understanding mathematical relations, (3) counting skills, and (4) basic skills in arithmetic (p. 684).

Despite different perspectives, there is a consensus on the necessity of improving number sense skills (Gülbağcı Dede, 2015). According to NCTM (1989), number sense skills cover (1) understanding the meaning of numbers, (2) establishing the relationship among numbers, (3) comprehending the relative magnitudes of numbers, (4) understanding the effects of operations on numbers, and (5) developing and using reference points in the cases that require measuring (p. 38). Number sense provides flexibility in using the information on numbers and operations, enables its effective transfer to daily life, shape the ways of mathematical thinking in years to come (Yang & Wu, 2010), and supports the development of useful and flexible strategies for problem solving that involve numbers and operations (Yang & Sianturi, 2019a, 2019b). Furthermore, Jordan et al. (2009) found number sense to be a predictor of computational fluency, running memory span and spatial reasoning skills. It has been concluded that children with poor number sense have insufficient counting and operation skills, logical reasoning approaches, and understanding and using the relationships between numbers and operations (Burns, 2007). Thus, poor sense concerning numbers and operations leads to challenges in mathematics teaching (Baroody & Rosu, 2006) and learning (Landerl et al., 2004; Mazzocco & Thompson, 2005).

Number sense that starts to be learned in early childhood and continues to develop in subsequent years of education is an important concept that should be learned and taught in mathematics education as it lays the foundation for learning mathematical concepts and establishing the relationships among them (Cheng & Wang, 2012; Mohamed & Johnny, 2010). Given the studies concluding that improvement of number sense skills increases

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mathematics achievements in years to come (Jordan et al., 2007; Mazzocco & Thompson, 2005; McGuire et al., 2012), lack of instruments that aim to identify number sense skills of primary school students raises concerns. Studies on number sense have been performed with pre-school students (Aunio et al., 2004, 2006; Howell & Kemp, 2010; Jordan et al., 2007, 2010), primary school students from Grade 1 to Grade 4 (Çekirdekci et al., 2016; Mohamed & Johnny, 2010; Olkun et al., 2015; Yang & Li, 2008; Zanzali & Ghazali, 2002), and elementary school students from Grade 5 to Grade 8 (Akkaya, 2016; Harç, 2010; İymen & Duatepe Paksu, 2015; Kayhan Altay, 2010; Kayhan Altay & Umay, 2013; Lin et al., 2016; Şengül & Gülbağcı Dede, 2013; Torbeyns & Verschaffel, 2016; Yang et al., 2008; Yapıcı, 2013), and preservice teachers (Gülbağcı Dede, 2015; Şengül, 2013; Şenol et al., 2015; Yaman,2015a, 2015b). Among these studies, there are limited number of research works about measuring number sense skills and test development, especially in primary schools. In addition, studies conducted in several countries (including Germany, Indonesia, Taiwan, and Hong Kong) have concluded that primary school students have poor number sense skills (Yang & Sianturi, 2021). It is also observed that the performance of Turkish students is below average in international exams such as Trends in International Mathematics and Science Study (TIMSS) and Programme for International Student Assessment (PISA) especially in numbers and operations (Mullis et al., 2012, 2016; PISA, 2014, 2018). The results of these exams indicate that children in these grade levels have incomplete knowledge originating from the primary school years. Accordingly, diagnosis provided in Grades 2–4 will be important for the mathematics achievement in the future.

Robust tests for measuring number sense would play a key role in monitoring the primary school students and taking appropriate precautions to eliminate their relevant deficiencies. Considering the international and national literatures as a whole, there is a limited number of tests measuring number sense on primary school level (e.g., Can, 2019 and Çekirdekci, 2015 for Grade 4; Yang and Li, 2008 for Grade 3). The number sense test developed by Can (2019) includes 10 context-based and 10 non-context-based items. It enables to examine the solutions used by the students in both contextual and non-contextual examples of the same problem. Number sense-based solutions are coded as 1 point and rule-based solutions as zero point to evaluate number sense performance of students. The number sense test developed by Çekirdekçi (2015) consists of two open-ended and nine multiple-choice items. The assessment is made as by scoring 4 points for correct number sense-based solution, 3 points for correct rule-based solution, 2 points for incorrect number sense-based solution, and 1 point for incorrect rule-based solution. The computerized/online number sense test of Yang and Li (2008) is composed of 25 multiple-choice items. Students were required to submit a correct answer and a reason for their choice for each test question. Four points are given for both correct answer and reason, 2 points are given for incorrect answer but correct reason, and 1 point is given for correct answer but incorrect reason. While the first two of these number sense tests for primary school level are implemented as paper and pencil based test whereas the third is administered as computer-based test. The test developed by Can (2019) reveals how number sense differs between context and non-context forms. The test developed by Çekirdekçi (2015) had 11 items. Measuring number sense skills with fewer items might pose a problem in terms of the reliability of test scores. The computerized number sense test developed by Yang and Li (2008) might have difficulties in terms of test administration, considering the technology skills of primary school students and the deficiencies in the technological infrastructure of the schools. In addition, all these tests were prepared for only one grade level at primary school level. Therefore, they only reveal the number sense performance at one grade and do not provide comparable results across grade levels. The number sense tests developed within the scope of our study have been prepared for Grades 2–4, and provided an opportunity to determine, to compare and to monitor the number sense performance of primary school students through proficiency definitions. Hence, this study aimed to develop tests for measuring and monitoring number sense skills of second, third, and fourth grade students and to compare their number sense skills according to gender, school type, and mother's educational level. Standing out among other instruments in the literature, this study focused on developing tests that involve anchor items so that identifying students' levels of number sense skills and their progress or shortcomings became feasible thoroughly. By the help of the proficiency definitions that were created

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based on the vertical equating, it became possible to categorize the number sense skills as basic, proficient, and advanced.

In the related literature, there are various factors such as teacher knowledge (e.g., Faulkner & Cain, 2013; Noviyanti, 2018; Tsao & Lin, 2012; Whitacre & Nickerson, 2006), textbook (e.g. Cheng & Wang, 2012; Sayers et al., 2021), and curricula (e.g. Dunphy, 2007; Reys, 1991) that can influence the improvement and performance in number sense. On the other hand, gender is emphasized as an important variable in developing number sense skills which are recognized as one of the main indicators of mathematics achievement (Fennema, 1990; NCTM, 2000). Research works concerning the gender differences have concluded that females and males have the same numerical skills in preschool (Dehaene, 1997; Nunes & Bryant, 1996); however, there are certain differences in primary school students' performance in problem solving and geometry in favor of males (Hall et al., 1999; Ma, 1995). Studies also show that females and males can differ by the strategies they use in mathematical problem solving in the first year of primary school; however, they do not differ by their performance levels (e.g. Carr & Jessup, 1997). It is also observed that gender differences in general and specific numerical skills are addressed in very few studies (Torbeyns et al., 2002; van de Rijt et al., 2003). In some studies, no significant difference by gender was found in number sense skills by Aunio et al. (2006) in preschool, by Menon (2004) in Grades 4–7, and by Yang and Li (2008) in Grade 3 whereas Singh (2009) concluded a difference in Grade 9 students in favor of males. In Turkey, no significant difference by gender was found in number sense skills by Çekirdekci (2015) in Grade 4, Kayhan Altay (2010) and Şengül and Gülbağcı (2012) in Grades 6–8, and a significant difference was observed in the use of number sense skills by Yapıcı (2013) in Grades 6–8. Understanding and recognizing the gender differences in mathematics will affect the future teaching and learning of mathematics (Yang & Li, 2008). On the other hand, studies showed that learning environment and classroom setting are important in improving number sense skills of students, and school and family plays a key role in this matter (Carneiro, 2008; Fiore, 2000; Greeno, 1991; Olkun et al., 2017; Reys, 1994; Yang & Hsu, 2009). It was concluded by Çekirdekci (2015) in Grade 4 students and Ivrendi (2011) in preschool children that there was no significant difference in number sense skills of students by mother's educational level. In the study conducted with Grade 6 and 8, Şahin (2018) observed that number sense scores increased as mother's education level increased and found a significant difference in students' number sense skills by whether their mother had been primary school, high school, or university graduate. On the other hand, a significant difference by school type was found in number sense skills by Koparan and Çataklı (2017) in Grade 7 and by Süel (2019) in Grades 6–8 in favor of private schools. Given these variables, there seems to be a limited number of studies about number sense. Hence, monitoring the development of number sense skills would be analyzed in terms of gender, school type, and mother's educational level, so that extensive information would be provided in this matter. In this vein, the following research questions guided this study:

RQ1. Are the number sense tests monitoring the performance for Grades 2–4 in the context of competencies reliable and valid?

RQ2. How do students' number sense skills differ according to gender, school type, and mother's education level?

## 3 | METHODS

### 3.1 | Participants

The number sense tests were administered to 2034 primary school students (653 second graders, 698 third graders, and 683 fourth graders) from both public and private schools in Turkey. The students did not come from different racial or ethnic backgrounds and did not have any disabilities. Moreover, the language of the test and the native language of the participants overlap. The frequency of the participants by gender, school type, and grade levels is given in Table 1.

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The statistics about the age of participants including the average, SD, minimum, and maximum values are presented in Table 2.

The distribution of participants' mother education level across grade levels is given in Figure 1.

Considering the mother's education level within the scope of grade levels, it is seen that there is not much difference in terms of proportion.

## 3.2 | Test development

Steps of developing the number sense tests for Grades 2–4 were handled within the framework of 12-step structure stated by Downing (2006) in the Handbook of Test Development.

**TABLE 1** Frequency of participants by gender, school type, and grade level

| | Public | | | Private | | |
|---|---|---|---|---|---|---|
| Gender | Grade 2 | Grade 3 | Grade 4 | Grade 2 | Grade 3 | Grade 4 |
| Female | 179 | 141 | 161 | 136 | 181 | 158 |
| Male | 173 | 168 | 201 | 165 | 208 | 163 |
| Total | 352 | 309 | 362 | 301 | 389 | 321 |

**TABLE 2** Statistics about the age of participants

| Grade level | Average (months) | SD | Max (months) | Min (months) |
|---|---|---|---|---|
| Grade 2 | 82.40 | 3.90 | 97 | 77 |
| Grade 3 | 95.02 | 3.98 | 111 | 88 |
| Grade 4 | 106.15 | 3.94 | 124 | 100 |

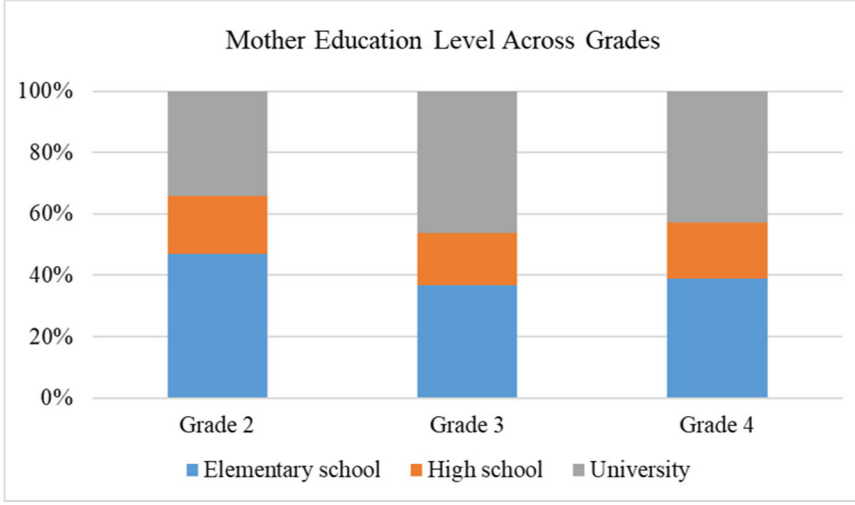


**FIGURE 1** Distribution of mother education level across grades

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### 3.2.1 | Step 1: Overall plan

In this stage where a systematic framework involving the developmental process of the test was created, general structure of the number sense skills to be measured was defined and the subdimensions were determined. It was decided that number sense skills would be composed of items in three subdimensions within the framework of standards that were defined by NCTM (2000) for numbers and operations briefly as (1) understanding the numbers and their properties, (2) understanding the operations and their properties, and (3) making meaningful estimations. The third subdimension in NCTM standards also involve computational fluency. However, computational fluency requires a speed-based performance so it was excluded from number sense tests.

### 3.2.2 | Step 2: Content definition

The content of the test needs to be defined for interpreting the test scores properly. In this step, how number sense would be addressed under the subdimensions of numbers, operations, and estimation on different grade levels was decided in consideration of the skills and learning outcomes specified in the mathematics curriculum.

### 3.2.3 | Step 3: Test specifications/blueprinting the test

This step requires a detailed discussion on the operational definitions for the test specifications. Accordingly, number and type of items to be included in the tests for each grade level were identified. It was also planned how difficulty levels of the items would be distributed and for which cognitive processes the items would be prepared, and how long the administration of tests should take was stated as well. Then, it was decided that each final test form of number sense for Grades 2–4 would consist of 20 items including multiple-choice and open-ended items. Therefore, the item writers planned to create more than 20 items in case of eliminating items during the test development. In addition, the test developers thought to involve easy items by 25%, items having moderate difficulty by 50%, and difficult items by 25% for a more reliable instrument.

### 3.2.4 | Step 4: Item development

The items were developed by two faculty members specialized in mathematics teaching within the specified test plan. Initially, the number of items for the tests of Grades 2, 3, and 4 were 24, 23, and 27, respectively. In this step, the scoring rubrics were also created. Next, two reviewers each specialized in mathematics education and primary education reviewed the items for simplicity, suitability for grade levels, understandability by students, and which subdimension of number sense the item was written for. Then, the reviewers solved the items independently and compared their responses with the scoring rubric. For matching the items with the subdimensions of number sense, to find the measure of agreement between the item writers and the two reviewers, Fleiss Kappa coefficients were calculated as 0.86, 0.81, and 0.83 for grades 2, 3, and 4, respectively. These values correspond to almost perfect agreement between the item writers and reviewers in matching the items with subdimensions (Landis & Koch, 1977).

In the pilot administration of the tests 148 second graders, 147 third graders, and 158 fourth graders from one public school and one private schools participated. The item analysis was conducted by Test Analysis Program—TAP (Brooks & Johanson, 2003) software to increase test effectiveness. TAP is a classical test and item analysis program which provides reports for examinee total scores, item statistics (e.g., item difficulty, item discrimination, point-biserial), options analyses, and so forth. The outputs of the program reported whether items needed revision and

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whether there was any distracter that did not work for multiple-choice items. Cronbach alpha reliability coefficients of the tests were calculated to be 0.77 for Grade 2, 0.74 for Grade 3, and 0.82 for Grade 4. These internal reliability coefficients are acceptable for Grades 2 and 3 and on a good level for Grade 4 (George & Mallery, 2003).

For evaluating the item bias, differential item functioning (DIF) analyses were conducted by using the *difR* package (Magis et al., 2012) of R software in regard to gender and school type. It was aimed with the DIF analyses to investigate the potential items working differently for separate subgroups. Based on the outputs of three of the most popular DIF detection methods, Logistic Regression, Mantel–Haenszel, and Lord's Chi-square methods, it was found that two items (Item 4 and Item 5) of Grade 2 caused bias in regard to gender and school type, respectively. It was also observed that one of the Grade 4 test item (Item 7) caused bias in regard to gender and two items (Item 1 and Item 3) of the same test caused bias in terms of school type. These items were omitted from the tests and by considering the test content, 20 high-quality items depending on the item parameters and point-biserial coefficients in each grade level were included in the final test forms. The distribution of the items by sub-dimensions of number sense is given in Table 3.

Following the pilot administration analyses, the final test forms were created, and the scoring rubric was updated based on the given responses in the pilot study.

### 3.2.5 | Step 5: Test design and assembly

Anchor items were used to equate the number sense tests across grade levels. Accordingly, the incomplete test design indicating number of test items is given in Figure 2.

In Figure 2, the numbers with gray background indicate the number of anchor items. Exemplary items from the number sense tests are given in Figure 3.

### 3.2.6 | Step 6: Test production

After final test forms had been created, they were printed out to review for readability by considering font type, size, and quality of images. Next, test forms were copied as many as the number of participants, and the copies were checked for any possible erratum.

**TABLE 3** Number of items in each sub-dimension across grade levels

| Sub-dimensions | Grade 2 | Grade 3 | Grade 4 |
|---|---|---|---|
| Understand numbers and their properties | 8 | 9 | 10 |
| Understand operations and their properties | 6 | 6 | 6 |
| Make meaningful estimation | 6 | 5 | 4 |
| Total | 20 | 20 | 20 |

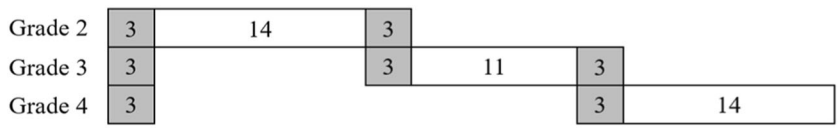


**FIGURE 2** Incomplete test design indicating the number of test items

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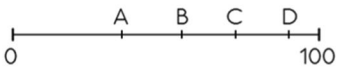
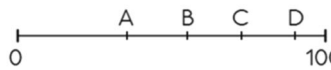
| Grade | Sub-dimension | Original version | English version |
|---|---|---|---|
| 2 | understand numbers and their properties | 79 sayısı aşağıdaki sayı doğrusunda hangi harfe karşılık gelir?<br> | Which letter corresponds to 79 on the number line given below?<br> |
| 3 | understand operations and their properties | <br>Yukarıda yer alan A kutusundaki sayıların toplamı B kutusundaki sayıların toplamından kaç fazladır? İşlem yapmadan bulunuz. | <br>How much greater is the sum of the numbers in the box A than box B? Find the solution without doing a written calculation. |
| 4 | make meaningful estimations | 1 litrelik su şişesi yaklaşık kaç adet su bardağını tam olarak doldurulabilir?<br>A) 2<br>B) 5<br>C) 25<br>D) 50 | Approximately, how many cups could you fill with 1 liter of water?<br>A) 2<br>B) 5<br>C) 25<br>D) 50 |

**FIGURE 3** Exemplary items of number sense test for each grade

### 3.2.7 | Step 7: Test administration

Certain standards need to be met for test administration. Forty minutes were given to each participants to take the test. It was ensured that the students took the tests in a comfortable setting and in almost the same conditions.

### 3.2.8 | Step 8: Scoring responses

Possible student responses in the scoring keys were utilized to score the responses provided for multiple-choice and open-ended items in the tests. Correct responses were coded as 1 and incorrect responses were coded as 0. A two-stage scoring process was employed to provide objectivity in scoring. Accordingly, the responses were scored by two different raters, and the inter-rater reliability between the scores was found to be 99.6%. Responses with inconsistent scoring were examined, and following the agreement, scoring keys of the relevant items were updated. Since responses to the items were scored as 0 or 1, tetrachoric factor analysis was performed to provide evidence for construct validity. Kaiser-Meyer-Olkin (KMO) values that evaluate data's fit for factor analysis were calculated as 0.76, 0.65, and 0.90 for grades 2, 3, and 4, respectively. The significance level of Bartlett's test was observed to be $p < .001$ in the analysis for all grade levels. According to tetrachoric factor analysis results performed with FACTOR (Lorenzo-Seva & Ferrando, 2006), explained variances were found as 48.87% for Grade 2, 48.25% for Grade 3, and 47.22% Grade 4 by three-factor structure of number sense skills. In other words, these percentage values indicate that almost half of the total variance in number sense tests is explained by these three factors.

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### 3.2.9 | Step 9: Establishing passing scores

Item Response Theory (IRT) analyses were utilized to establish the cut scores that define the proficiency levels. Instead of a pass-fail decision, cutoff scores were defined to create proficiency definitions of basic, proficient, and advanced levels for each grade level. In the analyses using vertical equating between the grade levels by means of anchor items, item parameters and the skill levels of all participants were predicted through a two-parameter logistic model of IRT. Accordingly, ability estimations for third-graders were equated as mean of 0 and SD of 1. Some statistics of item parameters are presented in Table 4.

The Bookmark method based on item mapping was used for setting the standards. An essential feature of this method is the use of IRT to "map" items onto a proficiency distribution where cut scores (standards) are set (Karantonis & Sireci, 2006). This method was preferred as it can be applied to the tests using multiple-choice and open-ended items at the same time (Cizek & Bunch, 2007). Items used in each grade level were ranked by their item difficulties, and the values where a jump was present in item difficulty parameters were determined as a potential cutoff point. Next, test developers took the item descriptions into account to decide between which items the cutoff points should be placed. Cutoff scores were calculated by determining the proficiency level of a participant who gave the correct response to all test items in the relevant proficiency level. Expected A Posteriori (EAP) method (Bock & Aitkin, 1981) was utilized for the ability estimation which used posterior distribution. The graphical representation categorizing the number sense skills as being basic, proficient, and advanced and through which their progress could be monitored in this study performed for all grade and proficiency levels is shown in Figure 4.

**TABLE 4** Statistics concerning item parameters of number sense tests

| | Item discrimination | | Item difficulty | |
|---|---|---|---|---|
| Grade | Mean | SD | Mean | SD |
| 2 | 0.77 | 0.33 | 0.23 | 1.20 |
| 3 | 0.83 | 0.32 | 0.71 | 1.24 |
| 4 | 0.81 | 0.29 | 1.20 | 0.75 |
| Overall | 0.81 | 0.31 | 0.64 | 1.21 |

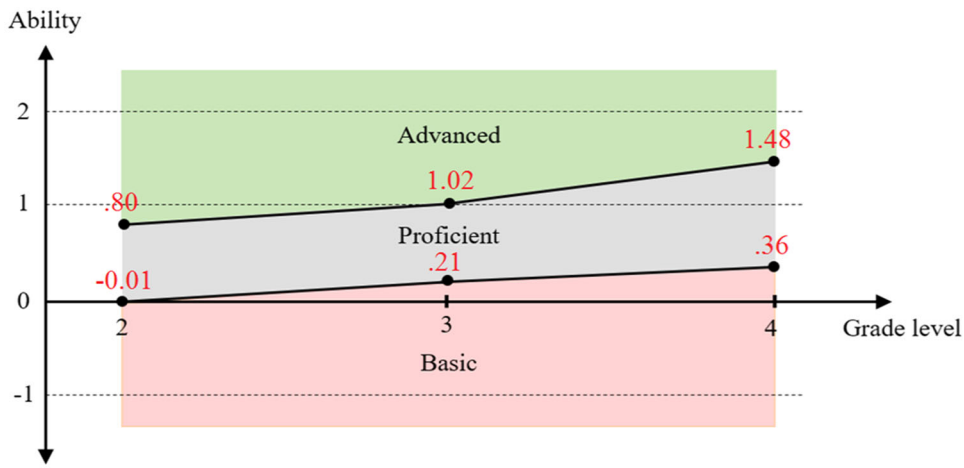


**FIGURE 4** Cutoff scores across grade levels

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In Figure 4, vertical axis is the ability (theta) estimations and horizontal axis is the grade levels. The cutoff scores were given in red color and they were used to monitor the development of number sense skills across grade levels. Accordingly, placing ability estimations on this figure provided clues about the proficiency levels of the participants.

#### 3.2.10 | Step 10: Score reporting

Test scores give information about the performances. Scores, mostly represented as numbers, do not merely give information about what the participants could or could not do. Depending on item properties and cutoff scores, the proficiency definitions for each of the basic, proficient, and advanced number sense skills have been stated in Table 5.

These proficiency definitions were formed by using the learning outcomes of the national mathematics curriculum (Ministry of National Education [MoNE], 2018). This mathematics curriculum covers learning domains, goals, subject matter, and learning outcomes. The number and percentage of students in each proficiency level across grade levels are shown in Figure 5.

Figure 5 showed that the number of students in the basic level was higher than the number of students in the proficient and advanced levels.

#### 3.2.11 | Step 11: Item banking

As time and effort spent were considered, item development is a costly process. Thus, test developers kept the administered test forms and the data in a safe environment and took all precautions for item security.

#### 3.2.12 | Step 12: Test technical report

A test technical report was created, including overall test plan, statistical analysis of the items, cutoff scores, and proficiency definitions for number sense tests.

### 3.3 | Validity and reliability issues

Reliability is the degree to which measures are free from error and provide consistent results (Thanasegaran, 2009). One of the key types of reliability is the internal consistency, which stands for the consistency of results across multiple items within a test (Fitzner, 2007). In the current study, the internal consistency coefficients of the final test forms were found as 0.76, 0.73, and 0.79 for grades 2, 3, and 4, respectively. These values indicated that the tests provided reliable results (George & Mallery, 2003). Interrater reliability refers to the consistency of scoring (Fitzner, 2007). When the raters provide similar scores, a higher interrater reliability is obtained. In the current study, the responses were scored by two raters, and the inter-rater reliability between the scores was found to be 99.6%. This consistency level is due to the well-defined scoring key. On the other hand, the bias is defined as the existence of a characteristic in an item that causes individuals of the same ability from different groups to perform differently (Hambleton & Roger, 1994). To check this situation during the test development, DIF analysis was held to evaluate the item bias.

Validity has been defined as the extent to which a test measures what it intends to measure (Gregory, 1992). The scope of the test was formed in the table of specifications by considering learning outcomes and number sense skills. With the expert opinions, it was aimed to ensure the content validity of the test. Moreover, the tetrachoric factor analysis findings have been reported as proof of the construct validity of the tests. The outputs of FACTOR

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(Lorenzo-Seva & Ferrando, 2006) showed that explained variance was found as 48.87% for Grade 2, 48.25% for Grade 3, and 47.22% Grade 4 by three-factor structure of number sense skills. The external validity, as it is commonly referred to, is whether the results of research works would be generalizable for other persons, settings, times, or places (Calder et al., 1983). In the final administrations of this study, a large sample was selected from different school districts, school types, and grade levels for better representation of primary school students and increasing the generalizability of research findings.

**TABLE 5** Proficiency definitions across grade levels

| Grade | Proficiency level | Proficiency definition |
|---|---|---|
| 2 | Basic | Set the rule of a pattern given within daily life context. Make meaningful estimations for determining the number of objects in a routine problem. Estimate the sum in an addition. Explain the relationship between repeated addition and multiplication. Recognize the commutative property in multiplication. Show half and quarter of a whole on the model |
| | Proficient | Make meaningful estimations for determining the number of objects in a nonroutine problem. Comprehend the relationship between addends and sums in a given problem. Determines whether a quantity is closer to a quarter, a half, or a whole. Compare the magnitudes of quantities formed by wholes, halves, and quarters within the daily life context |
| | Advanced | Estimate the approximate place of a two-digit number on a number line. Express a quantity of which is smaller than 100 on a number line. Estimate the length of an object within a given context. Evaluate the possible solutions that makes the result of a multiplication greater/smaller. Solve nonroutine problems that require multiplication with natural numbers |
| 3 | Basic | Create a number pattern. Make a numerical estimation on a routine problem Add odd and even numbers. Identify the relationship between addends and sums. Solve routine problems that require addition of natural numbers. Comprehend the relationship between repeated addition and multiplication. Determine whether a quantity is closer to a quarter, a half, or a whole. Show unit fraction of a whole |
| | Proficient | Round at most three-digit natural numbers to the closest tens or hundreds. Estimate the result of subtraction with natural numbers and compare with the result. Show the unit fraction of a quantity within the daily life context. |
| | Advanced | Estimate the length of an object within the given context. Solve nonroutine problems that require addition and subtraction with natural numbers. Do mental multiplication of two-digit natural numbers by 25 and 50. Solve nonroutine problems that require two operations, one of which is multiplication. Evaluate current situations so that result is greater in a multiplication. Recognize relationship between grouping of objects and division. Estimate the approximate place of a unit fraction on a number line |
| 4 | Basic | Create increasing and decreasing number patterns and determine the rule. Round three-digit natural numbers to closest tens or hundreds. Identify relationship between addend and sum in a routine problem. Find unknown value in a mathematical expression. Recognize relationship between multiplication and division. Identify unit fraction within daily life context |
| | Proficient | Express the length of an object. Estimate sum of two natural numbers. Estimate the result of subtraction and compare with the result. Make meaningful estimations within daily life context. Show unit fraction on the model. Do addition and subtraction of fractions with equal denominators |
| | Advanced | Do mental multiplication of two digit natural numbers by 25 and 50. Estimate the multiplication of two natural numbers and compare with the result. Evaluate current situations so that result is greater in a multiplication. Explore the relationship between dividend, divisor, and quotient in a division. Estimate the approximate place of proper, compound, and mixed fractions on the number line |

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### 3.4 | Further comparative analyses across grade levels

Using the developed number sense tests, it was investigated whether there were significant differences in number sense skills of Grade 2–4 students according to gender, school type, and mother's educational level. Two-way ANOVA was utilized in the analyses to investigate the mutual effect of the interaction between two independent variables rather than investigating their effects individually.

## 4 | RESULTS

The ability estimations of the participants were examined by gender (female vs. male), school type (public school vs. private school), and mother's education level (primary school vs. high school vs. university). Statistics containing the mean value of ability estimations and the standard error (SE) values of gender, school type, and mother's education level across grade levels are presented in Table 6.

Results in Table 6 suggest that while females were more successful than males in Grade 2, the mean value of males caught up with the mean value of females in Grade 3, and then, increased in Grade 4 with a statistically

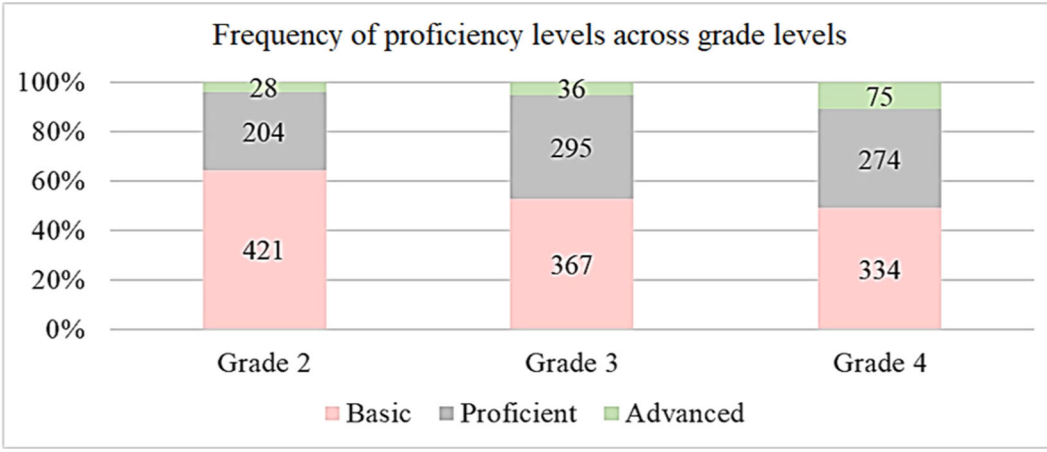


**FIGURE 5** Frequency of proficiency levels across grade levels

**TABLE 6** Ability estimations by gender, school type, and mother's education level across grades

| | | Grade 2 | | Grade 3 | | Grade 4 | |
|---|---|---|---|---|---|---|---|
| Variable | Category | Mean | SE | Mean | SE | Mean | SE |
| Gender | Female | −0.41 | 0.05 | −0.03 | 0.05 | 0.34 | 0.05 |
| | Male | −0.49 | 0.05 | 0.01 | 0.05 | 0.50 | 0.05 |
| School | Public | −0.60 | 0.05 | −0.08 | 0.05 | 0.23 | 0.05 |
| | Private | −0.29 | 0.06 | 0.06 | 0.05 | 0.64 | 0.05 |
| Mother's education level | Primary school | −0.40 | 0.06 | 0.10 | 0.06 | 0.40 | 0.05 |
| | High school | −0.29 | 0.09 | 0.25 | 0.08 | 0.50 | 0.07 |
| | University | −0.08 | 0.07 | 0.40 | 0.05 | 0.82 | 0.05 |

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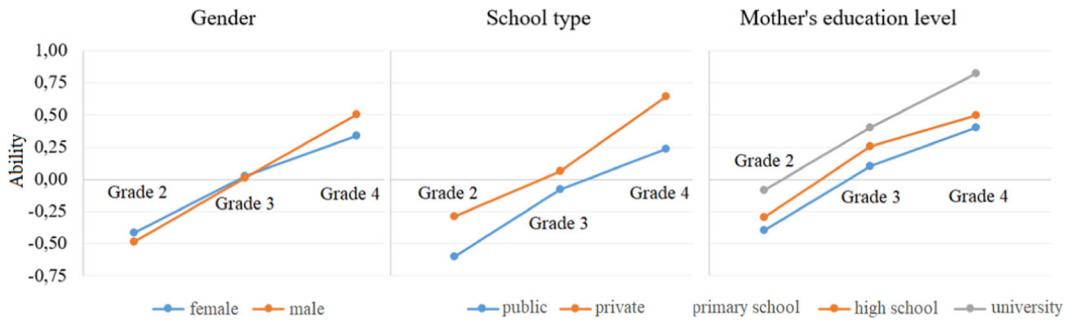


**FIGURE 6** Ability estimations by gender, school type, and mother's educational level across grades

significant difference in favor of males. The mean values of ability estimations indicated that the private school students' number sense skills were higher than the public school students' in all grade levels. As mother education level increased, it was seen that students had higher number sense skills. The additional analyses concluded that there was no significant difference in Grade 2 ($p = .313$) and Grade 3 ($p = .855$) by gender while there was a difference in Grade 4 ($p = .030$) in favor of males. The analyses conducted to determine whether number sense ability estimations differed in Grades 2, 3, and 4 by school type indicated that there were significant differences between Grade 2 ($p = .000$) and Grade 4 ($p = .000$) in favor of private school students. Despite a difference in Grade 3 in favor of private school students, this difference was not significant ($p = .058$). The findings show that number sense skills of the second, third, and fourth graders differed by mother's education level ($p = .000$). The mother's education level has a three-group structure (primary school, high school, and university) so post hoc analyses were performed. A significant difference was only found between primary school and university in favor of university in Grade 2 ($p = .001$). Significance values were found to be $p = .595$ between primary school and high school and $p = .131$ high school and university, and no significant differences were found between these groups by ability estimations. The analyses on whether ability estimations differed by mother's education level in Grade 3 achieved similar results as in Grade 2. Accordingly, although a significant difference was observed between primary school and university graduation of mothers in favor of university ($p = .000$), no significant differences were found between primary school and high school ($p = .259$) and high school and university ($p = .255$). In Grade 4, ability estimations were observed to significantly differ between high school and university ($p = .001$) and also primary school and university ($p = .000$) in favor of university level. Nevertheless, the difference between ability estimations of the students whose mothers were graduates of primary school and high school was not found to be statistically significant ($p = .527$). A more convenient observation of the above-mentioned differences in the ability estimations by gender, school type, and mother's education level across grade levels is shown in Figure 6.

## 5 | DISCUSSION

This study focused on developing number sense tests that monitor the development of number sense skills across Grades 2, 3, and 4. Number sense tests consisted of three sub-dimensions as (1) understanding numbers and their properties, (2) understanding operations and their properties, and (3) making meaningful estimation. In the tetrachoric factor analysis for construct validity of the number sense tests, Kaiser–Meyer–Olkin (KMO) values that evaluate data's fit for factor analysis were calculated to be 0.76, 0.65, and 0.90 for Grades 2, 3, and 4, respectively. The significance level of Bartlett's test was observed to be $p < .001$ in the analysis for all grade levels. Students' number sense skills were found to be explained by the three-factor structure by 48.87% for Grade 2, 48.25% for Grade 3, and 47.22% Grade 4. In other words, these percentage values indicate that about half of the total variance

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in the number sense tests is explained by these three factors. It is thought that some of the unexplained variance was due to the fluent computation which could not be included in this study. Cronbach alpha reliability coefficients of the tests were found to be 0.76, 0.73, and 0.79, respectively. For assessing the tests, number sense skills were classified as basic, proficient, and advanced levels. After determining the cutoff scores, proficiency descriptions of each level were defined based on the item characteristics.

The findings of the study showed that second, third, and fourth graders performed poorly in the number senses tests. Of the second graders, 65% were on the basic level, 31% were on the proficient level, and 4% were on the advanced level in terms of number sense skills. Of the third graders, 53% were found to be on the basic level, 42% to be on the proficient level, and 5% to be on the advanced level in terms of number sense skills. Of the fourth graders, 49% were observed to be on the basic level, 40% to be on the proficient level, and 11% to be on the advanced level in terms of number sense skills. Simply, the students of each grade level had poor, and mainly basic number sense skills, and only very few of them had advanced skills. Similarly, number sense skills were observed to be poor by Yang and Li (2008) among third graders and by Can (2019) and Çekirdekci (2015) among fourth graders. These findings also coincide with the results achieved for the number sense skills of elementary school students (Grades 5–8) in the international and national literatures (Harç, 2010; Iymen & Duatepe Paksu, 2015; Kayhan Altay, 2010; Markovits & Sowder, 1994; McIntosh et al., 1997; Reys & Yang, 1998; Reys et al., 1999; van den Heuvel-Panhuizen, 2001; Verschaffel et al., 2007; Yang, 2005; Yang et al., 2004; Yoshikawa, 1994). Poor performance values observed both in this study and other studies performed on the primary school level indicate that deficiencies in number sense skills emerge much before the elementary school level and that intervention should begin as of the primary school years to improve these skills among students (Yang & Li, 2008).

While the study concluded that the mean value of ability estimations for females was higher than for males in Grade 2, mean value ability estimations of males became almost equal in Grade 3. In Grade 4, ability estimations of males exceeded females. However, the results also showed that there was no significant difference between the number sense skills of the second and third graders by gender. Most of the studies in the literature support these findings (Aunio et al., 2006; Çekirdekci, 2015; Harç, 2010; Kayhan Altay, 2010; Menon, 2004; Şengül & Gülbağcı, 2012; Yang & Li, 2008). However, a significant difference was found in the number sense skills in Grade 4 in favor of males. Similarly, Singh (2009) and Yapıcı (2013) concluded that males were better than females at number sense skills. The results achieved with regard to gender on the primary school level seem to be substantially similar to the results on the elementary school level. Selected sample, age group, region of the study, and differences among countries might have been the factors behind the different results concerning the gender.

The mother's education level, addressed in this study, was found to cause a statistically significant difference in number sense skills of the second, third, and fourth graders. A significant difference was found in all three grade levels between number sense skills of the students whose mothers' education level were primary school and university in favor of university graduate. Moreover, there was a significant difference between number sense skills of the fourth graders whose mothers' education level were high school and university in favor of university. One can therefore argue that as the level increased, mother's education level had a positive impact on students' number sense skills. Upper education levels mean more complexity of subjects taught to children and broader scope of skills expected from them. Accordingly, students of upper grade levels may need parental assistance even more to overcome these challenges. It was observed in the study that there was an increase in students' number sense skills as mother's education level increased from primary school to high school and from high school to university. Şahin (2018) achieved similar results; Çekirdekci (2015) and Ivrendi (2011) found no significant difference in students' number sense skills by mother's educational level.

In this study, a significant difference was concluded between number sense skills of the public and private school students in Grades 2 and 4 by school type. While there was no significant difference in number sense skills of the third graders by school type, the private school students were found to be more successful in number sense skills in all grade levels. Both Süel (2019) and Koparan and Çataklı (2017) concluded that private school students had better number sense skills than public school students. Similarly, Aunio et al. (2006) found school type to affect

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number sense skills due to the differences in teaching and cultural structure. Classroom settings, activities, instructional methods, and contents used by teachers play a key role in the improvement of number sense skills as in every subject (Tsao, 2005; Tsao & Lin, 2011; Yang et al., 2009). Hence, teacher performances vary by the school and facilities of the school. Number sense skills of the private school student might have been better since private schools in Turkey are institutions that put much effort to support student development in many dimensions and to provide a systematic teaching compared to public schools. In line with the results concerning the number sense skills on the basis of mother's education level and school type, several studies have shown that environmental conditions and learning settings are effective in improving number sense skills of students, and school and family play a key role in this matter (Carneiro, 2008; Fiore, 2000; Greeno, 1991; Olkun et al., 2017; Reys, 1994; Yang & Hsu, 2009).

One element that affects improvement of number sense skills in students is teachers. Notably, there are studies which concluded that teachers and preservice teachers have poor number sense skills (Kaminski, 2002; Şengül & Gülbağcı Dede, 2014; Şengül, 2013; Tsao, 2005; Yang, 2007; Yang et al., 2009). Given the impact of teacher's knowledge and skills on students, it is thought that lacking in this matter has a negative effect on students' number sense skills. Whitacre and Nickerson (2006) attributed the improvement of number sense skills in students to better number sense skills of teachers. It has been also concluded in several studies that students prefer rule- and operation-based strategies rather than number sense skills when solving test items (Menon, 2004; Reys et al., 1999; Yang & Li, 2008; Zanzali & Ghazali, 2002). In this regard, it is emphasized that teacher tendencies to use rules when teaching mathematics present a hindrance before the improvement and usage of number sense skills (Gülbağcı Dede, 2015; Kilpatrick et al., 2001; Yang & Li, 2008). Concentrating on standard written computational algorithms in mathematics instruction is regarded as another approach that hinders the improvement of number sense skills as it prevents thinking skills such as reasoning and estimation from emerging (Burns, 1994; Hiebert, 1999; Kamii et al., 1993; Reys & Yang, 1998; Yang, 2005; Yang & Reys, 2002). Moreover, another element that affects the improvement of these skills is thought to be the coverage given to number sense skills in mathematics curricula and textbooks. Cheng and Wang (2012) stress out that mathematics curricula are an important factor that affects mathematics learning and student progress in number sense skills is supported through textbooks. Studies that examine mathematics curricula in Turkey indicate the lack of gains about number sense and of relevant activities (Gülbağcı Dede, 2015; Şengül, 2013; Umay et al., 2006). The insufficiency of teacher knowledge, textbook content, and curricula might have been some of the prominent reasons behind students' poor number sense skills.

## 6 | CONCLUSIONS AND IMPLICATIONS

Several studies have shown that students of different grade levels have poor number sense skills (Reys & Yang, 1998; Reys et al., 1999; van den Heuvel-Panhuizen, 2001; Verschaffel et al., 2007; Yang, 2005; Yang & Li, 2008; Yang et al., 2004). A similar result was achieved in this study, and it was observed that school type could be an effective factor in improving the number sense skills and mother's education level could make a contribution to the improvement. While gender was observed to have no effect in lower grade levels, it was concluded that difference could occur as the grade level increased. Since the role of gender on number sense skills could not be clearly understood, there seems to be a need for further study.

Inadequacy of gains and activities about improving number sense in mathematics education is considered one reason for poor skills among students. It is emphasized that classroom settings, which support communication, research, discussion, thinking and logical reasoning, an appropriate instructional content and well-designed activities should be created in mathematics education (Markovits & Sowder, 1994; Yang, 2003). Teaching the number sense should focus on conceptual comprehension and guide students toward meaningful learning (Yang, 2003). Yang and Li (2008) state that number sense is a topic that should be emphasized in mathematics curriculum

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to make significant progress in mathematics education and that activities about number sense skills should be integrated into textbooks as of lower grade levels.

In this study, we developed tests for demonstrating the number sense performance, describing the number sense competencies and monitoring the development of number sense skills of second, third, and fourth grade students. According to Yang and Li (2008), poor number sense performance of higher grades might be traced back to earlier grades. Therefore, the tests we developed in our study are thought to be important for identifying the change and deficiencies in number sense skills of students in primary school, which represents the first few years of education and for allowing teachers to change the teaching plans accordingly. Computational fluency as the third dimension of number sense in NCTM (2000) standards was excluded from the content of tests because it requires a speed-based performance; this presents a limitation of the study. It is thought that computational fluency can be added to future studies for developing computer-based number sense tests. It is observed in the literature that studies are mostly concentrated on identifying the number sense skills and are conducted with upper-grade levels. However, studies have shown that poor performance in number sense skills is rather seen among lower grade levels. Hence, it is notably necessary to increase the number of studies based on extensive observations or interventions aiming to improve number sense skills on the primary school level.

## CONFLICT OF INTEREST

The authors declare no conflict of interest.

## DATA AVAILABILITY STATEMENT

Research data are not shared.

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