THE EFFECT OF GAME-BASED LEARNING ON FOURTH-GRADE STUDENTS' NUMBER SENSE ABILITIES

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- this thesis contains no material that has been submitted or accepted for a degree or diploma in any other educational institution;
- this is a true copy of the thesis approved by my advisor and thesis committee at Boğaziçi University, including final revisions required by them.

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ABSTRACT

The Effect of Game-Based Learning

on Fourth-Grade Students' Number Sense Abilities

Number sense is an essential ability in mathematics learning, and it has shown to be predictive for early mathematics achievement. The dot enumeration and mental number line are acknowledged as the primary systems of number sense predicting mathematical skills. Previous research has focused on improving number sense abilities of preschoolers or younger children, however; there are not enough studies examining the effect of video games on the number sense improvement of fourth grade students. The current study explored the effects of specifically designed game-based learning activities on fourth grade students' number sense development. The activities were designed with a 3-D video game, namely Minecraft. The study employed a sequential explanatory mixed method design. The participants were 4th-grade students (n = 21) from a private school in İstanbul. The intervention was carried out twice a week for four weeks (25-40 minutes each time). The results of hierarchical regression analysis showed that mathematics achievement, executive functions, and working memory performances predicted dot enumeration and mental number line performances. After the video-game intervention, hundred and thousand mental number line scores were improved significantly. The qualitative findings indicated that typically and high achieving students used mathematical strategies such as rounding, proportional judgment, and mental arithmetic when performing number line tasks on video games and created larger groups when performing dot enumeration. Overall, the findings of the study indicated that game-based learning activities were effective for improving fourth-grade students' number sense skills.

ÖZET

Oyun Temelli Öğrenmenin

Dördüncü Sınıf Öğrencilerinin Sayı Duyusu Becerilerine Etkisi

Nokta sayılama ve sayı doğrusu tahmini, matematiksel becerileri öngören sayı duyusunun bileşenleri olarak kabul edilmektedir. Bu alandaki çalışmalar, okul öncesi ve ilk yıllardaki sayı duyusu gelişimini kapsamaktadır, ancak dördüncü sınıf öğrencilerinin sayı duyusu gelişimini video oyunu müdahalesi ile araştıran yeterli sayıda çalışma yoktur. Araştırmanın amacı üç boyutlu bir video oyunu (Minecraft) aracılığıyla tasarlanmış öğrenme aktivitelerin dördüncü sınıf öğrencilerinin sayı duyusu gelişimi üzerindeki etkilerini araştırmaktır. Araştırma deseninde sıralı açıklayıcı yöntem uygulanarak nicel ve nitel veriler analiz edilmiştir. Katılımcılar, İstanbul'da bulunan özel bir okuldaki 4. sınıf öğrencilerdir (n = 21). Öğrenme aktiviteleri dört hafta boyunca haftada iki kez yaklaşık 25-40 dakika olarak uygulanmıştır. Bu çalışmada nokta sayılama yeteneğinin yürütücü işlevler (engelleyici kontrol ve dikkat kontrol) ve çalışma belleği (görsel-uzamsal bellek) olarak ölçülen genel bilişsel yeteneklere bağlı olduğu hiyerarşik analiz sonuçlarına göre bulunmuştur. Video oyunu, yüz ve bin sayı doğrusu son-test puanları önemli ölçüde geliştirmiştir. Nitel bulgular, yüksek ve ortalama başarılı öğrencilerin video oyunu üzerinde nokta sayımı yaparken daha büyük gruplar oluşturduklarını ve sayı doğrusu görevlerini gerçekleştirirken, yuvarlama, orantı hesabı ve zihinden aritmetik gibi matematiksel stratejiler kullandığını ortaya çıkarmıştır. Araştırmanın bulguları video oyununun dördüncü sınıf öğrencilerinin sayı duyusu becerilerini geliştirmede etkili bir araç olduğunu göstermiştir.

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ABBREVIATIONS

BNPT: Basic Number Processing Test

CDC: Canonic Dot Counting

CT: Corsi Task

GNGT: Go-No-Go Task

IES: Inverse Efficiency Score

MAE: Mathematics exam averages

MNL: Mental Number Line

NS: Number Sense

PSTS: Problem Solving Test Scores

RDC: Random Dot Counting

SNC: Symbolic Number Comparison

ST: Stroop Task

VSWM: Visual-Spatial Working Memory

WMB: Working Memory Battery

CHAPTER 1

INTRODUCTION

"Pure logical thinking cannot yield us any knowledge of the empirical world; all knowledge of reality starts from experience and end in it." -Albert Einstein

Humans obtain knowledge of the empirical world through experiences rather than deliberation. Experiences can be categorized as first-person experiences: personal, direct, implicit, and third-person experiences that are social, indirect, and explicit (Winn, 1993). We may exemplify first-person experiences as riding a bicycle, constructing a building, being in a historical place or a museum, conducting experiments in a science lab. In this form of experience, humans' perception of the world directs their action without the interference of consciousness. In contrast, the third-person approach defines experience as a result of predictable action, which can be analyzed through detailed exploration of the human brain (Chalmers, 1996). Although the former cannot be thought of as superior to the latter, new conceptions are shaped around prior conceptions, which are affected by personal experience.

Information in schools is still mostly presented in the form of third-person symbolic statements, but people learn better by first-person experiences (Winn, 1993). For example, observing bacteria under the microscope is a first-person experience, while reading a textbook about the cell structure of the bacteria is a third-person experience. Thomas and Brown (2011) define a new learning culture that occurs outside of the classroom and without books, that is, learning through play, games, and imagination. This type of learning does not take place by knowledge transference, but it takes place by an act of questioning and a passionately engaging learning environment (Thomas et al., 2011).

Video games have a considerable potential to provide learners with immersive and imaginative environments. In the context of this study, the potential of playing video games to improve the number sense (NS) of fourth-graders is explored. Many different cognitive abilities affect students' achievement in mathematics, and one of them is number sense. Number sense is an essential ability in mathematics learning, and it has shown to be predictive for early mathematics achievement (Hornung, Schiltz, Brunner, & Martin, 2014; Jordan, Glutting, & Ramineni, 2010; Jordan, Kaplan, Locuniak, & Ramineni, 2007; Locuniak, & Jordan, 2008; Starr, Libertus, & Brannon, 2013). Number sense is a complex mathematical ability predicting "higher-order" mathematical thinking that begins to develop in infancy and can be developed through mathematics instruction (Berch, 2005; Xu & Spelke, 2000).

There are various definitions of number sense, and in the context of this study following definition was used as the framework. Cognitive psychologists define NS as an approximate number system including subitizing, counting, and number line estimation (Deheane, 2001; Booth & Siegler, 2006). The subitizing ability, or, more precisely, subitization, arise from a Latin word of "subitus," which corresponds to the word of sudden, occurs in a short duration of time, that is about five- or six-tenths of a second to recognize an array of three dots, and this duration is not constant gradually increase from 1 to 3 objects (Deheanae, 2011, p.57). Thus, the subitizing ability can be referred to as an instant enumeration of 1-3 objects.

Furthermore, having evolutionary roots, the mental number line (MNL) is an analogical representation of the number that forms a basis for arithmetic (Dehaene, 2011). Many studies are exploring the ability of mental number line of children, and in this research, Booth and Siegler's (2006) study provides a framework

to understand and explain mental number line levels and strategies of fourth-graders used during mental number line video game tasks.

Many research studies explored the relationship between number sense and mathematics achievement. Research in mathematics education suggests that number sense development makes a considerable yet unique contribution to students' mathematics achievements from different grade levels (Halberda, Mazzocco, & Feigenson, 2008; Holloway & Ansari, 2009; Jordan, Kaplan, Nabors Olah, & Locuniak, 2006). Yang, Li, and Lin (2007) found a significant correlation between 5th grade students' mathematics achievement and their number sense abilities. Predicting second-grade mathematics achievement, number sense measures of kindergarten students were the most decisive variable among age, reading, memory, and verbal and spatial cognition (Locuniak et al., 2008). In a longitudinal study controlling general intelligence in childhood, there was a significant relationship between approximate number sense acuity and mathematics abilities of 6 months and 3.5-years old children (Starr et al., 2013).

Students have individual differences regarding their number sense abilities, which stem from prior experience, learning opportunities, and innate abilities (Jordan et al., 2006). According to the National Council of Teachers of Mathematics (NCTM) curriculum standards, whole number concepts and skills should be established in the K-4 mathematics curriculum to promote number sense development in later grades (Sowder, 1992). In 2018, the Turkish Ministry of National Education (MEB) primary mathematics curriculum standards included number sense-related abilities in the mathematics curriculum. Number sense-related objectives were referred to as estimation, mental calculation, and calculation fluency, but "number sense" was not mentioned (MEB, 2018). Additionally, mathematics

curriculum evaluation studies revealed that the number sense related objectives were decreased between 2009 and 2017 (Karabey, Tunalı, Olkun, & Ergut, 2019), and the number sense ability was not stated clearly (Çetin & Öztürk, 2020). As previously stated, number sense improvement has a considerable effect on mathematics achievement. Therefore, adverse learning effects of eliminating number sense related objectives are more likely to be observed in the long run (Karabey et al., 2019).

The number sense ability can be improved through training, and computer-based methods are found to be effective (Kucian et al., 2011; Kuhn & Holling, 2014). Research has been focused on improving NS by using board games and digital games in 2D dimension such as Bingo, Wuzzit trouble, The Number Race (Laurillard, 2016; Nejem & Muhanna, 2013; Obersteiner, Reiss, & Ufer, 2013; Pope & Mangram, 2015; Sella, Tressoldi, Lucangeli, & Zorzi, 2016; Siegler & Ramani, 2008; Wang & Hung, 2010; Wilson et al., 2006). The use of video games in mathematics education is not a new research area; however, there is no such study to improve the exact number and mental number line abilities through 3D videogames.

To sum up, experimental studies and existing literature imply that improving NS is essential for developing mathematical skills. Video games have considerable potential to motivate learners, increase engagement during instruction, and promote positive attitudes toward mathematics. Levin (1981) found that video games motivated and engaged learners, and the use of video games effectively taught mathematics concepts by addressing different learning styles.

The study aims to provide learners with authentic and immersive number sense activities by using the strengths of video games. Minecraft was identified as one of the most popular video games globally, and the game was integrated into standardized curricula of the schools in the USA and Sweden (Karsenti, Bugmann, &

Gros, 2017). Additionally, NCTM (2000) suggests video game integration in mathematics lessons, and Minecraft: Education Edition (MinecraftEdu) is on the recommended list. In this study, the MinecraftEdu video game was used as an intervention tool to improve students' number sense abilities.

1.1 Significance of the study

Previous research has focused on improving the number sense abilities of first graders, preschoolers, or younger children (Honoré, & Noël, 2016; Ramani, Daubert, & Scalise, 2019). However, there are not enough studies examining the effect of video games on improving the number sense abilities of older children (Maertens, De Smedt, Sasanguie, Elen, & Reynvoet, 2016), particularly fourth graders. The current study aimed to address this gap by designing and implementing instructional activities in a virtual game environment to improve number sense abilities. Participants, therefore, had the opportunity to develop their number sense abilities which is an essential skill for their success in mathematics courses. In addition, the use of a widely known virtual game as an instructional tool had a potentially positive effect on students' motivation towards mathematics lessons.

In addition, the findings of this research had the potential to provide benefits for policymakers, mathematics teachers, and researchers. Also, mathematics teachers could gain insight into ways of supporting their mathematics lessons with Minecraft Education Edition. Finally, researchers would be benefited from the results of the study whether videogames have a considerable potential to improve the number sense abilities of fourth-grade students.

Considering educational research studies, no scientific studies investigated the development of number sense skills using video games. The current research is a primary source in this context.

1.2 The Purpose of the study

The current study examines the effects of the specifically designed instructional activities in a virtual game environment on the number sense abilities of fourth-grade students. Additionally, the role of number sense on fourth-grade mathematics skills and general cognitive abilities was explored.

1.3 Research questions

This study attempted to answer the following research questions:

1.Potential effect of videogames on number sense development

Is there a significant difference between pre-test and post-test number sense scores of fourth-grade students who completed number sense tasks in the virtual game environment?

2. The role of mathematics achievement and executive functions in dot enumeration performances.

a) How much do mathematics achievement and problem-solving skills of fourth-grade students explain variance in random dot counting performances when controlling for executive functions and working memory?
b) How much do mathematics achievement and problem-solving skills of fourth-grade students explain variance in canonical dot counting performances when controlling for executive functions and working memory?

3. The role of mathematics achievement and working memory in mental number line gains.

a) To what extent do mathematics achievement and problem-solving skills of fourth-grade students explain variance in the ten number line gains when controlling for executive functions and working memory?
b) To what extent do mathematics achievement and problem-solving skills of fourth-grade students explain variance in hundred number line gains when controlling for executive functions and working memory?
c) To what extent do mathematics achievement and problem-solving skills of fourth-grade students explain variance in thousand number line scores when controlling for executive functions and working memory?

4. How do students with different number sense gains use number sense strategies?

1.4 Research hypotheses

H1: The students' pre-test number sense scores measured by the Basic Number Processing Test will be lower than the post-test number sense scores after completing number sense tasks in the virtual game environment.

H2: Random dot enumeration performances of students are explained by mathematics achievement and problem-solving when controlling for working memory performances and executive functions performances.

H3: Canonical dot enumeration performances of students are explained by mathematics achievement and problem-solving when controlling for working memory performances and executive functions performances.

H4: Mathematics achievement and problem-solving are predictive for ten number line gains when controlling for working memory performances and executive functions performances.

H5: Mathematics achievement and problem-solving are predictive of hundred number line gains when controlling for working memory performances and executive functions performances.

H6: Mathematics achievement and problem-solving are predictive of thousand number line gains when controlling for working memory performances and executive functions performances.

CHAPTER 2

LITERATURE REVIEW

This research was primarily concerned with the following topics: (1) the definition of number sense (2) the role of executive functions, school mathematics achievement, and problem-solving skills in explaining individual differences in number sense development, (3) the potential effect of video games on number sense development. Accordingly, the previous literature was reviewed and presented in this section.

2.1 The number sense as a mathematical concept

Although the origin of the term was debatable (McIntosh, Reys J., & Reys E., 1992), NS had its roots in history, and it was mentioned even in the last 1800s by famous psychologist John Dewey (1898). For almost two hundred years, number sense became one of the central topics of many studies investigating numerical cognition in humans. The researchers' attention in understanding NS has led many definitions to arise.

NS and definitions of NS entered the scope of two fields which were mathematics education and cognitive psychology. Mathematics education studies investigate the development of NS in K-12, mostly in preschool and elementary school years, while cognitive psychology studies investigate the development of NS from infancy to adulthood. Furthermore, mathematics educators and cognitive psychologists attribute different cognitive competencies when explaining NS. In the scope of this research, a cognitive neuroscientist, Stanislas Dehaene's definition is used, which refers to NS as "a short-hand for our ability to quickly understand, approximate, and manipulate numerical quantities" (Dehaene, 2001, p.2). NS

consists of cognitive abilities in subitizing, counting, and mental number line (Dehaene, 2001). Subitizing skill is defined as the instant and correct enumeration of a small collection of objects from 1 to 3 or 1 to 4 (Revkin, Piazza, Izard, Cohen & Dehaene, 2008). Counting is a more complex process than subitizing (Liu & Wong, 2020), requires people to recognize the objects on the screen, monitor and memorize the items that are already counted, and spot the remaining items (Dehaene & Cohen, 1994). Lastly, the mental number line (MNL) is an intuitive-spatial map of the numerical quantity constructed from left to right (Dehaene, 2011). The components of NS will be organized separately, and more detail will be given later under the related headings.

On the other hand, the development of NS in schooling is attributed to have a general understanding of number and operations (McIntosh et al., 1992; Yang, 2005), tendency to manipulate the numbers flexibly in the creation of useful strategies (McIntosh et al.1992), flexible mental computation, numerical estimation, and quantitative judgment (Greeno, 1991), in addition to these skills to carry out mental mathematics and to compare magnitudes (Berch, 2005; Gersten & Chard, 1999). Furthermore, Sowder (1992) stated that NS is as complex as problem-solving, and it cannot be reduced to a simple definition, but NS can be incorporated as the competency in numeration, number magnitude, mental computation, and computational estimation.

In the above paragraphs, NS was defined from the perspectives of cognitive researchers and mathematics education researchers. As mentioned earlier, NS is a complex cognitive ability, and it cannot be reduced to a single definition. On the other hand, whichever definition we use, there is a clear consensus that NS is a critical skill for higher mathematics abilities (Henik, 2016; Matejko & Ansari, 2018),

and the effect of NS skills on students' mathematics achievement is undeniable. Therefore, educators should consider identifying NS in the early years of schooling and integrating number sense activities into mathematics lessons to support students with low performances.

2.1.1 Mathematics achievement and number sense

The current studies have focused on the relationship between mathematics achievement and NS ability. Understanding numbers, relations among numbers, and numerical magnitudes are necessary for numerical cognition's early development (Henik, 2016). From infancy to adulthood, the numerical development process includes: (1) representation of increasing magnitude of numbers, (2) relating non-symbolic representations with symbolic numbers, (3) expanding understanding from smaller to larger whole numbers, and (4) accurately representing the magnitudes of rational numbers (Siegler, 2016).

Non-symbolic number knowledge, namely preverbal number sense, is a foundational number competency that begins to develop in infancy, and it can be improved significantly in the early years of schooling (Jordan & Levine, 2009). Infants' preverbal number sense was found to be predictive of their mathematical abilities in kindergarten (Starr, Libertus & Brannon, 2013). On the other hand, number magnitude knowledge in whole and rational numbers was predictive for mathematical understanding, arithmetic, and overall mathematics achievement longitudinally (Siegler, 2016). NS, therefore, needs to be improved in the early years of childhood to lead to mathematics achievement later on.

NS continues to develop in elementary years and predicts mathematics achievement in higher grades. In a study, first graders' mathematics achievement was

explained by 66 percent of variance with NS performances and NS gains in preschool years (Jordan, Kaplan, Locuniak, & Ramineni, 2007). Özdem and Olkun (2019) found that second and third-grade students who received two months of training in conceptual subitizing increased their scores in Turkish curriculum-based mathematics achievement tests as well as competencies in arithmetic operations.

Moreover, first, second, and third grades of students' scores in a curriculum-based math achievement test were correlated significantly with the NS performance tasks, including symbolic comparison and number line estimation tasks (Sasanguie, Göbel, Moll, Smets, & Reynvoet, 2013). Estimation skills of fourth-grade students in number line estimation tasks were correlated with their competencies in numeracy and operations (Link, Nuerk, & Moeller, 2014). Schneider et al. (2018) studied estimation skills of children whose ages varied between 4 and 14 and asserted that the number line estimation task was a powerful tool to determine and predict mathematics competencies, including counting, arithmetic, and school achievement.

2.1.2 Subitizing skill and counting skill as the components of NS

Children use two methods to determine the exact number of objects in a representation, and these methods are subitizing and counting (Clements & Sarama, 2014; Liu & Wong, 2020). Subitizing refers to the rapid and precise enumeration of objects up to 3 or 4 (Clements, 1999; Cohen & Dehaene, 2008; Liu & Wong, 2020; Mandler & Shebo, 1982; Revkin, Piazza, Izard; Trick & Pylyshyn, 1993). Children far more quickly determine the number of objects up to 3 or 4, which is less than one-fifth of a second (40-200 msec/item) compared to more than 4 objects (250-350 msec/item (Trick, & Pylyshyn, 1994).

Counting, apart from being a serial mechanism, is exact and slower than subitizing (Formoso et al., 2017). Schleifer and Landerl (2011) found that children reach maximum capacity in subitizing (i.e., at age 8) before enumeration ability (i.e., at age 11). It was also found that highly competent students in canonical dot enumeration outperformed students with mathematical difficulties regarding subitizing range and counting range performances (Schindler, Schovenberg, & Schabmann, 2020).

Some believed that subitizing skill was a part of estimation skill that shows high precision rates (Gelman and Gallistel, 1986). However, it is argued that subitizing skills cannot be regarded as advanced estimation skills (Revkin, Piazza, Izard, Cohen, & Dehaene, 2008). Revkin et al.'s (2008) study refer to subitizing skill as a separate system for enumeration of objects in small numerosity from 1 to 4, as performances in subitizing tasks and performances in large-number tasks do not correlate with each other. They found that participants' estimation accuracy shifted from linear to logarithmic representation model when participants were shown dot arrays from 1 to 10 for more than 4 objects. Participants responded far slower in larger sets; therefore, there was no linear relationship between the magnitude of set and response times (Revkin et al., 2008). For example, if one enumerated two objects in .25 seconds, it was not true that they would enumerate six objects in .75 seconds. It is expected to observe a longer response time.

Asserting Dehaene's (2011) definition of subitizing skills and counting skills, we follow Revkin et al. (2008) 's arguments and regard the experimental results obtained in their study as the findings that determine the direction of this research. Thus, the quantity of objects up to 4 is determined quickly, and this innate ability, subitizing, is different from counting.

Moreover, we intended to investigate subitizing skills and counting strategies of children in the number collections, including objects from 1 to 10. The base of this intention comes from Gelman and Gallistel's (1986) contradictory argument that states subitizing process involves some level of counting and it is not direct apprehension of numerosity. In the current research, we argue that subitizing process is a separate system differentiating from counting, and we seek to find consistent results with our argument by conducting quantitative analysis.

The current research investigates the effect of number sense video game tasks on fourth graders by analyzing the difference between pre-test and post-test enumeration scores of 1-10 objects. Additionally, in the analysis of the interviews, Revkin et al.'s (2008) argument is followed to understand students' subitizing and counting processes during the video game tasks. Therefore, subitizing and counting skills of children were explained and explored as integrated but separate constructs.

2.1.3 Mental number line estimations as to the components of NS

Humans have an innate mental number line oriented from left to right (Dehaene, 2011; Di Giorgio et al., 2019; Longo & Lourenco, 2007) and unconsciously place small numbers to the left and large numbers to the right (Felisatti, Laubrock, Shaki, & Fischer, 2020). For example, people place 1 and 2 to the left, 8 and 9 to the right.

The precision in estimating mental number line (MNL) depends on age and experience of the child (Moeller, Pixner, Kaufmann, & Nuerk, 2009; Schneider, Grabner, & Paetsch, 2009; Siegler, 2016). Even though competency in the MNL has biological roots, the estimation accuracy can be developed through instruction. Indeed, computer games were found to be effective for developing MNL skills of

children from preschool to age ten (Kucian et al., 2011; Käser et al., 2013; Maertens, De Smedt, Sasanguie, Elen, & Reynvoet, 2016; Siegler & Ramani, 2009).

Children use various strategies when performing MNL estimation, and MNL estimation requires the effective use of counting and arithmetic skills (Petitto; 1990; Schneider et al., 2008), in addition to proportional judgment (Barth & Paladino, 2011). Furthermore, it was found that MNL estimation strategies developed significantly through the first three years of elementary grades, and only older children used proportion strategy, namely the mid-point strategy (Ashcraft & Moore, 2012; Heine, 2010; Petitto, 1990; Schneider et al., 2008). That is, students perform estimation by approximating the middle point of the number line. On the contrary, younger children were able to use sequential counting strategies by starting from the beginning point or end point of the number lines (Petitto, 1990, Schneider et al., 2008).

The MNL estimation skills were acknowledged as predictive for mathematics achievement (Link, Nuerk, & Moeller, 2014; Schneider et al., 2018; Simms, Clayton, Cragg, Gilmore, & Johnson, 2016). Moreover, MNL evaluation can be diagnostic for children with dyscalculia (Kohn et al., 2020; Kucian et al., 2011; Lafay, St-Pierre, & Macoir, 2017). Children with less precise estimations in mental number line tasks were most likely to have difficulties in arithmetic, mathematical problem solving and comparing magnitudes (Link, Nuerk, & Moeller, 2014; Schneider et al., 2018).

To conclude, the mental number line abilities were essential for mathematics achievement. To determine and support students with less precise mental number line estimations, evaluation of mental number line skills and early intervention developing those skills are required.

2.2 The role of executive functions in number sense ability

2.2.1 Executive functions and working memory capacity

Experimental psychologists and neuropsychologists differ in conceptualizing attentional control, which are working memory capacity (WMC) and executive functioning (EF), respectively (McCabe, Roediger, McDaniel, Balota, & Hambrick, 2010). However, strong correlations between measures of WMC and EF were found (*r* = *.97*, McCabe et al., p.222). In this study, inhibitory control was explained as one of the components of executive functions. Working memory capacity was explained as a system that strongly correlates to measures of executive functions as a component of working memory.

2.2.2 Inhibitory control, attentional control, subitizing, and counting

There is a connection between executive functions and children's mathematical skills (Bull & Scerif, 2001). Maintaining goal-directed behaviors, executive functions consist of operations that are response inhibition, regulation of performance, updating task demands, goal maintenance, planning, working memory, and cognitive flexibility (McCabe et al., 2010). In particular, response inhibition (i.e., inhibitory control) is related to counting and calculation (Purpura, Schmitt, & Ganley, 2017).

First, inhibition takes place in counting and subitizing ability. According to attentional theory (Trick, Audet, & Dales, 2003), enumeration consists of the following steps: (1) objects are divided into clusters, (2) attention is directed toward a specific cluster and objects are subitized in that cluster, (3) the sum of the cluster hold in working memory, (4) counted objects are crossed off to avoid recounting which we called as inhibition, (5) the same steps repeated until all clusters crossed off, (6) the sum of all objects are held in working memory and articulated (Trick,

Audet, & Dales, 2003, pp. 1230-1231). Schleifer and Landerl (2011) demonstrated that visual scanning was vital to count accurately, and children did not have adult-like competence in counting before 11 years old. Therefore, inhibitory control is essential for counting, particularly during the process of object tracking on the screen.

Moreover, subitizing and counting are attention-demanding processes (Olivers & Watson, 2008), which depend on different attentional systems (Simon & Vaishnavi, 1996). The counting process requires selective eye movements, which is not required when subitizing (Simon & Vaishnavi, 1996; Watson, Maylor, & Bruce, 2007). If the array includes many dots, the patterns became less familiar, causing reduction of enumeration efficiency; therefore, enumeration of large sets requires more attentional resources (Olivers & Watson, 2008; Railo, Koivisto, Revonsuo, & Hannula, 2008).

Clayton and Gilmore (2015) suggest that controlling individual differences in inhibitory control will be critical to measure the relationship between mathematics achievement and dot comparison tasks. In the current research, children's dot enumeration performances were explored as one of the components of NS, performances in attentional control and response inhibition tasks were explored as the control variables.

2.2.3 Working memory capacity: visuospatial short-term memory

There are different approaches regarding human working memory. Baddeley (1992, p.556) defines working memory as "a brain system that provides temporary storage and manipulation of the information necessary for such complex cognitive tasks as language comprehension, learning, and reasoning." Working memory is responsible

for concurrent storage and processing information, and it consists of three components: central executive and two slave systems: the visual sketchpad and the phonological loop (Baddeley, 1992). The slave systems are regarded as working independently from each other (Baddeley, 1992), and competency in enumeration and mental number line estimation are found to be dependent on visual-spatial working memory (VSWM) performances (Bachot, Gevers, Fias, & Roeyers, 2005; Chan & Wong, 2019; Fischer, Castel, Dodd, & Pratt, 2003; Formoso, Barreyro, Jacubovich, & Injoque-Ricle, 2017, Ranzini, Carbè, & Gevers, 2017; Stoianov, Kramer, Umiltà, & Zorzi, 2008).

Formoso et al. (2017) measured VSWM with the Corsi block tapping test and found that VSWM performances and subitizing and counting abilities of 4- and 6-years old children were positively correlated. Indeed, there was a negative correlation between the mean response times of enumeration measures and VSWM measures (Formoso et al., 2017).

The general cognitive abilities are not independent of each other. Even though the working memory span tasks measure the limit of visual-spatial working memory capacity, attention is widely recognized as the limiting factor of the working memory capacity (original reference as cited in Howard, Johnson, & Pascual-Leone, 2014). Along with the visual-spatial working memory performances, attention performances were determined as predictor variables to explain variances in enumeration and mental number line estimation performances.

2.3 The potential effect of video games on number sense development

2.3.1 Theory behind game-based learning

In the early 1950s, Jean Piaget's cognitive developmental theory brought a new understanding of children's mental development processes. Human cogitative and verbal intelligence were devoted to the biological factors as well as reconstructed habits and associations (Piaget & Cook, 1952). Piaget (1976, pp. 11-12) stated three explanations for the cognitive development process: (a) cognitive development of an organism depended on interactions with the environment to adapt (b) the adaptation of intelligence depended on information obtained through experience (c) organism's "epistemological relations constructed by continuous interaction between the subject and the external world." In accordance with Piagetian view, learners' experiences must be excelled to improve learning as humans construct knowledge through experiences with the environment.

Van Eck (2015) stated that the educational potential of digital games stems from the pedagogy behind game-based learning, which coincides with situated learning and authentic problem-solving. People develop skills by evaluating the stimuli, and stimuli-rich environments promote learning and perceptual development (Hammond, Austin, Orcutt, & Rosso, 2001).

Increasing engagement and motivation of the learners yield positive outcomes for learning. Newman (1992) defined engagement as students' affective investment in learning, understanding, and developing knowledge as well as skills related to the objectives of the course. Fin and Zimmerman (2012, p.99) provided the following six principles to promote engagement and to decrease drop-out rates; "reforms that encourage voluntary choice on the part of students and student participation in policy decisions, maintain clear and consistent educational goals, keep school sizes-small,

encourage cooperative student-staff relationships, and provide an authentic curriculum."

As stated above, the instructional activities need to be thoughtfully selected to arouse students' interest and to motivate students to maintain the learning activity. This became even more important in 2020, the year when education was sustained under the negative influence of the Covid-19 pandemic. Daniel (2020) refers to the Covid-19 outbreak as the biggest challenge education has faced in the last 50 years worldwide. Schools are closed for the sake of social distance and to decrease the spread rate. Unfortunately, 1.53 billion learners away from schools that means 87.6 percent of enrolled learners across the world, were negatively affected by the closure (as cited Akat & Karataş, 2020). The curriculum should be designed to motivate and interest learners to increase participation and attendance in remote lessons. Therefore, instructional activities and curricula need to be modified during remote learning (Daniel, 2020).

2.3.2 Video games as learning tools

Baby Boomers, Generation X, Generation Y.1, Y.2 (Millennials), and Generation Z are the names of four generations that were born in the last 80 years (Dimock, 2019). When defining generations, Pew Research Center (2019) took 1997 as the end year of Millennials and the beginning year of Gen Z. Millennials and Gen Z were more exposed to digital games and video games among other generations in particular. Therefore, video games became potential tools to explore cognitive and behavioral effects on GenZ.

Changes and improvements in the digital world alter habits followed by experiences. Video games are one of the influential parts of software technology that

take a considerable amount of monetary and time investments by players as well as developers (Barr et al., 2007). Human-computer interaction studies explore how video games take part in everyday life and influence human behaviors. Game players spend plenty of time and effort in front of their computers and game consoles. The reason for players' intense presence in a virtual world and engagement with the game tasks is not only because the games are entertaining but also the players enter into a new world to learn something (Shaffer, Squire, Halverson, & Gee, 2005).

As with movies and books, most video games include a story that engages players from the beginning to the end. James Paul Gee (2003) differentiates playing video games from watching movies and reading books as he states that when watching movies and reading books, the mind engages with the scenario whereas the body is in a passive state. However, this is not the case as players attend in a virtual world or real one with "all the perceptions, actions, choices and mental simulations of action or dialogue" (Gee, 2003, p.82). Videogame players participate in the process with mind and body; the existence of the mind as a part of the body is called "embodied" (Gee, 2003).

The great popularity of video games has attracted the academic community's attention regarding "how video games work, what video games do, and what they could do" (Barr, Noble, & Biddle, 2007, p. 180). Game studies were conducted to reveal the effectiveness of the videogames in several areas such as military training, medicine, and education. However, the primary purposes of the educational game studies may be listed as follows: to investigate "whether, how, and what students learn from entertainment games," to evaluate learner engagement when developing serious games, and to determine which characteristics of games provide the best

learning outcomes during the development process of serious games (McNamara, Jackson, & Graesser, 2010, p.45).

There are certain types of video games, and serious games are among those concerning education through human-computer interaction. Serious games are first mentioned by Clark Abt (1970) as games produced for educational purposes and played by more than two players to accomplish goals. At the beginning of the twenty-first century, the term the serious game was referred to as "commercial video game technology" used for educational purposes (Annetta, 2008).

Serious games may boost motivation and keep learners engaged, but the goal is beyond engagement. Besides learning the subject matter, educational video games help learners improve skills such as problem-solving, self-monitoring, analytical and spatial skills (Graesser, Chipman, Leeming, & Biedenbach, 2009). Furthermore, having control over the game environment and taking responsibility for their learning provides learners with a personalized and autonomous learning style. Dynamic structures of the game environment allow learners for autonomy, active participation, and engagement.

Effects of videogame studies were explored by several fields such as psychology, psychiatry, medicine, and education (De Aguilera & Mendiz, 2003; Mifsud, Vella, & Camilleri, 2013; Steinkuehler & Squire, 2014). Indeed, the effect of video games attracted the attention of mathematics education studies. Therefore, the use of video games in mathematics education studies will be explained in the following sub-section.

2.3.3 Video games in mathematics education

The use of video games in education is not a new phenomenon, and many research studies are exploring the effect of video games on some subject areas such as language, history, geography, and mathematics learning (Steinkuehler & Squire, 2014). Levin (1981) found that video games motivated and engaged learners, and video games effectively taught mathematics concepts by addressing different learning styles. Devlin (2011) implies that videogames are enjoyable to keep players on the screen and satisfy curiosity.

Rosas et al. (2003) conducted a study to explore the effects of video games on learning, motivation, and classroom dynamics. This study showed that not the only experimental tool used in the study increased motivation and attention percentage of learners, but also disruptive behavior of students decreased (Rosas et al., 2003). A more recent meta-analysis study exploring the effects of videogame integrated mathematics education reported videogames as a beneficial educational tool that promotes motivation and increases performance in mathematics (Byun & Joung, 2018).

Besides affective domain gains of implementing video games in mathematics education, cognitive learning gains were provided in algebra learning (Bai, Pan, Hirumi, & Kebritchi, 2012), developing reasoning skills (Bottino, Ferlino, Ott, & Tavella, 2007), and overall mathematics achievement scores (Kappers, 2009). In particular, 3-D video games were embedded in mathematics courses to teach number-related concepts with Dimension-M (Gillispie, 2008) to explore 3D mathematics concepts with AquaMOOSE (Elliott, Adams, & Bruckman, 2002).

Moreover, specific mathematics topics and certain skills were assessed using video games (Kiili, Devlin, Perttula, Tuomi, & Lindstedt, 2015). Kiili et al. (2015)

used a video game named Wuzzit Trouble to improve mathematical thinking and problem-solving skills. They concluded that even short-duration game-based interventions might improve mathematical skills and help to assess mathematical knowledge.

NCTM (2011) provides six principles for making qualified educational decisions: equity, curriculum, teaching, learning, assessment, and technology. According to the technology principle of NCTM (2011), teachers can use the technology to evoke the students' interest and to increase their competency in mathematics. To conclude, video games provide many opportunities to excel in mathematics, perceptual development, and motivation compared to traditional instruction. This study explored the effect of Minecraft video games on fourth graders' number sense abilities.

2.3.4 The effect of videogames on number sense related cognitive abilities

Videogames are found to be interesting as their potential to improve cognitive abilities. Video games were effective tools in improvement of visual attention (García-Redondo, García, Areces, Núñez, & Rodríguez, 2019), spatial concentration and working memory (Zhangnet al., 2020), problem-solving, decision-making, collaborative work, creativity (Dondlinger, 2007; Green, Pouget, & Bavelier, 2010; Zea, Sánchez, Gutiérrez, Cabrera, & Paderewski, 2009).

Visual-spatial abilities, attention, and language-based processes are neurocognitive abilities that are related to mathematical development (Barnes & Raghubar, 2014). Visuospatial processing takes part intuitively in some aspects of number processing and calculation that is "the meaning of a digit in a multi-digit

number is coded following spatial information, given its association to its relative position within the number" (de Hevia, Vallar, & Girelli, 2018, p.1362).

An approximate number system (ANS) is related to visual-spatial processing performance. Research has revealed that 15-16 years old students with mathematical difficulties had poorer scores in visuospatial working memory (VSWM) tasks than their peers (Kyttälä, 2008). As there is a positive relationship between playing action videogames and visuospatial processing (Castro-Alonso & Fiorella, 2019), playing videogames was likely to improve number sense abilities.

2.3.5 Minecraft as a learning tool

This study explored the educational use of first-person video games. First-person video games are produced around a story and include the main character that stands for players identity through the gameplay. Minecraft: Education Edition game is a first-person video game that promotes creativity, collaboration, and problem-solving in an immersive environment (Foerster, 2017).

Minecraft is one of the most preferred video games among children, and many research studies are exploring the use of Minecraft video games in teaching (Karsenti et al., 2017). Foerster (2017) used the Minecraft game as a three-dimensional tool to enhance middle-grade students' spatial geometry skills. Al-Washmi et al. (2014) conducted a design-based study using the MinecraftEdu game to develop number and operation skills. The research team concluded that using MinecraftEdu was a beneficial tool to promote mathematics problem-solving, but it was needed to test in "formal" school environments.

2.3.6 Theoretical considerations of educational game design

The design of video games requires a considerable amount of time and effort as well as operating a theory-based scheme to create well-designed games. Kiili (2005) postulates a model that integrates educational theory and game design elements. The model includes three aspects which are experiential learning theory, flow theory, and game design (Kiili, 2005). In this study, Kiili's (2005) framework was used to design NS activities, and three aspects of the framework are explained in detail in the following paragraphs.

First, the experiential gaming model is based on the experiential learning theory of Piaget, Lewin, and Dewey (as cited in Kiili, 2005), which suggests learning occurs by direct experiences with the stimuli and observations about those experiences. Therefore, goal-directed behavior was sustained through first-hand experience and observation of feedbacks to those experiences (Kiili, 2005).

Second, the flow theory of Csikszentmihalyi provides designers a framework to create successful educational games to absorb and engage learners with optimal experience (as cited in Kiili, 2005). In this study, the following flow elements were used to evaluate learner experiences and the design game: achievable task, concentration, clear goals, feedback, effortless involvement, control over actions, concern for self-disappear, loss of sense of time (Csikszentmihalyi, 1990).

Third, Jeremy Gibson Bond's (2014) design framework was used to understand and explain game design elements, as the experiential framework does not provide a complete model for a game design project (Kiili, 2005). Therefore, Bond's (2014) Layered Tetrad framework was adopted to design Minecraft number sense tasks.

The Layered Tetrad framework suggests a game design model around four elements: mechanics, aesthetics, technology, and narrative (Bond, 2014). According to Bond (2014), it is essential to understand the Layered Tetrad's three layers clearly. As illustrated in Figure 1, the model represents a transfer of ownership from the game's developers to the game's players. The Inscribed Layer belongs to game developers and designers. The Dynamic Layer is where the game is truly experienced, so game designers want players to take action and make decisions so that games written by designers are truly experienced; finally, in the cultural layer, the control of the game transfers to players.

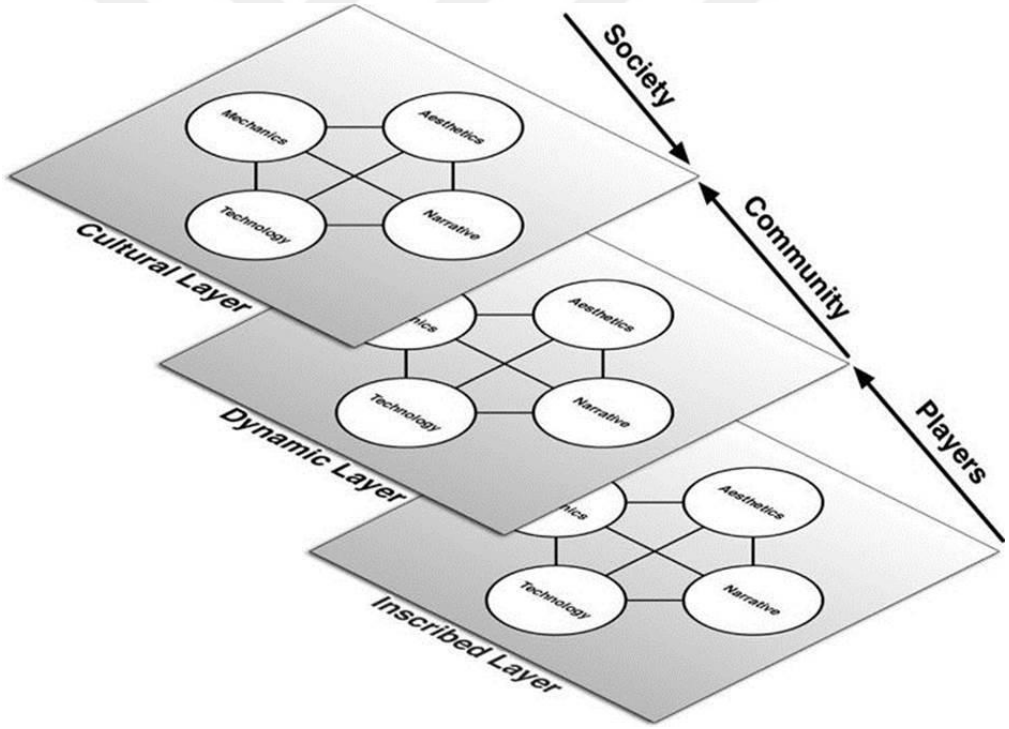


Figure 1. Layered Tetrad

Note. From "Introduction to Game Design, Prototyping, and Development: From Concept to Playable Game with Unity and C" by J. G. Bond, 2014, p.52

As the Inscribed Layer guides the designers (Bond, 2014), the elements of this layer will be unfolded as the following: (a) the mechanics refer to the way of

interactions between the player and the developer, (b) the aesthetics encapsulate how the game is seen, sounded and felt, (c) technology refers to digital technology how the game (e.g., Minecraft-number sense game) can be played, (d) narrative includes the rewards, characters, and plots (Bond, 2014).

First, the mechanics element of the inscribed layer includes objectives, player relationships, rules, boundaries, resources, and tables inscribed by designers. The aesthetic element consists of visual art, sounds, and music to alert and keep players in mood. The narration element includes the premise and the setting of the game. Minecraft number sense game was designed around a main story, which was saving the environment by fighting water pollution, global warming, drought, and deforestation. The inscribed technology in digital games allows the play of the game by programming. The Minecraft games were primarily programmed to navigate the player, to give the rewards, and to set the narration.

In conclusion, the Minecraft number sense activities were designed according to the experiential gaming approach, flow theory, and layered tetrad design framework (see appendix F). The game design elements, which were aesthetics, mechanics, technology, and narration, guided the activities in each map. Accordingly, all the possibilities that MinecraftEdu can offer have been researched and applied to design the number sense game. It is essential to point out that this was not a design study; however, the tasks were designed according to research-based game frameworks with considerable time and effort.

CHAPTER 3

METHOD

This chapter consists of detailed information about the methodology, research design, context and participants, the pilot phase, the treatment phase, instruments, and data analysis.

When selecting a research methodology, the aim is to find the best way to answer research questions. Therefore, the study was conducted with the sequential explanatory mixed methods design, which was the inclusion of quantitative and qualitative research approaches (Schoonenboom & Johnson, 2017). Creswell and Clark (2018) define sequential explanatory mixed methods design as " a mixed-methods design in which the researcher begins by conducting a quantitative phase and follows up on specific results with a subsequent qualitative phase to help explain quantitative results" (p.105).

Campbell and Fiske (1959) were first mentioned mixed methods as a multitrait-multimethod matrix by stating the inadequacy of one method for validation purposes. According to Subedi (2016), mixed methods have gained popularity in educational research, preventing methodological bias in explaining the phenomenon. Moreover, mixed methods provide a detailed analysis of the trends in the study results and the research problem by integrating quantitative and qualitative methods (Ivankova, Creswell, & Stick, 2006). In this study, quantitative and qualitative approaches were combined to improve validity and avoid a unilateral approach in understanding the research problem and analyzing study results.

The quantitative and qualitative phases of the research study have a unique contribution to examining the research problem. The former is used to test

hypotheses and make predictions by deduction, while the latter helps to explain what was found in the study by induction (Creswell & Clark, 2018). In this study, quantitative data analysis investigated correlation among outcome variables: number sense ability, and the predictor variables were working memory performance and mathematical problem-solving ability. After collecting quantitative data, a semi/ structured interview was employed to enrich and contradict numerical findings. Hence, qualitative analysis was employed to explore the individual learning experiences of the participants during the treatment.

3.1 Research Design

Explanatory sequential design type prioritizes the quantitative phase of the study followed by the qualitative phase (Creswell & Clark, 2017). Therefore, a single-group pre-test and post-test design were employed; afterward, interviews were conducted with a semi-structured interview design.

The outcome variables consisted of subskills of number sense ability which are: random dot enumeration performance, canonical dot enumeration performance, the ten number line gains, the hundred number line gains, and the thousand number line gains. The dot enumeration performances were referred to as the measures of inverse efficiency scores (Gary & Reeve, 2014), and the inverse efficiency score combines the accuracy and the speed to evaluate task performance (Bruyer, & Brysbaert, 2011).

The predictor variables were mathematics exam averages, mathematical problem-solving scores, and working memory performances. The mathematics exam average was calculated, and mathematical problem-solving scores were determined

using a mathematical problem-solving test (PST) (Olkun & Akkurt-Denizli, 2015; TIMMS, 2003, 2007, 2011).

Working memory performances were determined by a working memory battery which consisted of Stroop Task (ST), Go-No-Go Task (GNGT), and Corsi Task (CT) (Stoet, 2010, 2017). ST measured inhibitory control, GNGT measured attention, and CT measured visuospatial working memory.

Qualitative data was collected with semi-structured interviews. Rowley (2012) states that conducting a research interview requires a detailed plan of each step that is (a) design and planning interview, (b) conducting the interview, and (c) interpretation of interview data. The thoughtfully planned interview stages navigate the researcher through the study. Rowley (2012) implies that researchers need to question the reason of selecting interview method for the study at first. Conducting interviews is necessary when the researcher explores the study's phenomenology and reasons behind the participants' behaviours. In this study, individual interviews were conducted with participants to explore their game experiences and determine number sense strategies when they played the game.

Quantitative and qualitative approaches were integrated systematically, and qualitative and quantitative data were collected in accordance with procedures. To better describe the research design, a graphical representation of mixed methods explanatory sequential design was prepared (see Figure 2). The graphical scheme of the current study was adapted from a systematic outline of explanatory sequential design (Ivankova, Creswell, & Stick, 2006, p.16). Demonstrating priority of quantitative phase, the QUANTITATIVE phrase was written in initials as same as in the original model. In this scheme, quantitative and qualitative phases of research

and connections between these stages were expressed. The procedures and products of qualitative and quantitative approaches were written in detail.

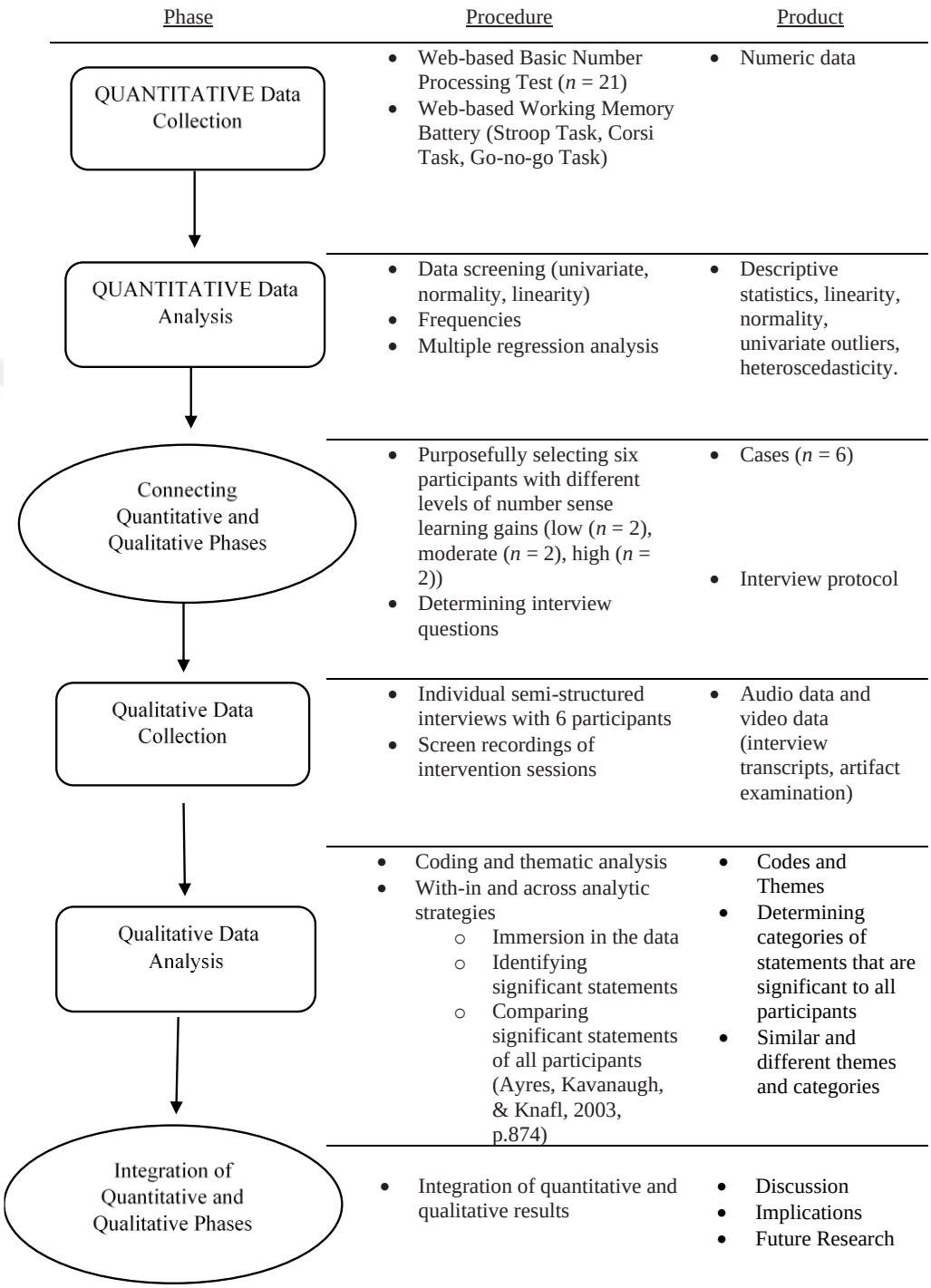


Figure 2. Graphical representation of mixed methods explanatory sequential design procedures

Note. Adapted from "Using Mixed-Methods Sequential Explanatory Design: From Theory to Practice," by N. V. Ivankova, J. W. Creswell, and S. L. Stick, 2006, Journal of Field Methods, 18, p.16.

3.2 Sampling and participants

The 21 4th grade students studying in a private school were the participants of this study. Participants were selected from a private school in İstanbul, where the researcher worked as a mathematics teacher. The consent from the principal, students, and students' parents were collected. Therefore, a non-probability sampling method which was purposeful sampling, was employed for site selection.

Creswell (2012) refers to the target population as the "sampling frame which contains a group of individuals with some common defining characteristics that the researcher can identify and study" (p.142). In the current study, the target population was identified as 4th-grade students who enrolled in private schools. The convenience sampling method is useful when the target population, a representative sample of study participants, is easy to access and available at research time.

Since the researcher's location was in İstanbul, the sample was selected as 4th-grade students studying at a private school in İstanbul. Therefore, the sample size was the number of 4th-grade students in private schools in İstanbul who were conveniently available to the study. Therefore, a non-probability sampling method which was convenience sampling, was used to select participants (Etikan, Musa, & Alkassim, 2016).

Creswell and Clark (2018) suggest that analysis of quantitative data of large number of individuals helps generalization of results while analysis of qualitative data helps in-depth understanding perspectives of small number of individuals. In this study, a single group included 21 participants, and they were 4th-grade students- in the 10-11 age range- in the selected school. Inclusion criteria of the qualitative phase were dependent on the setting of the study. Participants of the quantitative phase were selected according to the following criteria (a) 4th grade, (b) no

experience with 4th-grade number sense developing tasks, (c) no experience with game-based instructional activities. That is, six participants who had different levels of number sense learning gains (low (n = 2), moderate (n = 2), high (n = 2)) selected, and other subjects excluded.

3.3 Data collection instruments

The five instruments measuring number sense ability, working memory capacity, mathematical problem solving, and mathematics achievement were prepared and applied to students. Basic number processing test (BNPT) was applied in pre-test and post-test, and there was 108 days between the pre-test and the post-test. Additionally, an interview protocol was prepared and employed to understand participants' number sense strategies during game play.

3.3.1 Basic number processing test (BNPT)

The BNPT is a web-based instrument that was used to determine number sense scores of fourth-grade students. The instrument includes six tests which are random dot counting (RDC), canonical dotcounting (CDC), symbolic number comparison (SNC), and mental number line estimation (MNL) (Olkun, Akgün, & Sarı, 2020; Olkun & Akkurt-Denizli, 2015). Each test measures different subcomponents of number sense ability which are exact number system, symbolic number system, and approximate number system (Olkun et al., 2020). Random dot counting test consists of 21 randomly placed black dots in random quantity from 1 to 9 dots. Canonical dot counting (CDC) test includes 21 canonical randomly placed dots in random quantity from 1 to 9 dots. Symbolic number comparison test (SNC) consists of 24 questions that require comparison of numbers represented with different physical sizes of

mathematical number symbols (Olkun & Akkurt-Denizli, 2015). The questions include incongruent (e.g., 2 looks bigger than 5), neutral (e.g., 5 looks equal to 7), and congruent (e.g., 7 looks bigger than 5) conditions. The mental number line (MNL) tasks consist of questions asking the replacement of a given number on 0-10 number line, 0-100 number line, and 0-1000 number line.

3.3.2 Working memory battery: stroop task (ST)

Stroop task is a widely used instrument that measures one of the components of executive functions: inhibitory control and selective attention. It is acknowledged that inhibitory control correlates with children's mathematical achievement, and children's performance in stoop tasks determines the level of inhibitory control (Bull & Scerif, 2001; Cragg, Keeble, Richardson, Roome, & Gilmore, 2017; St Clair-Thompson & Gathercole, 2006). In this study, a digital Stroop task (see appendix B) was used to measure fourth-grade students' inhibitory control prepared by the PsyToolkit web page (Stoet, 2010, 2017).

3.3.3 Working memory battery: digital corsi block-tapping test (Corsi)

Corsi block tapping test or Corsi test is an instrument that is used to measure visuospatial short-term memory. Being responsible for visual information storage, the visuospatial sketch pad is one of the slave systems of executive functions (Passolunghi & Lanfranchi, 2012). In these tasks, participants are expected to tap in the correct order to the square blocks which appear on the screen in a sequence. Corsi block tapping test can be applied in the forward direction and in the backward direction. While corsi forward task requires tapping blocks in the same direction with the sequence, corsi backward task requires tapping correct blocks in the inverse

direction with the sequence. The minimum number of blocks is 1, and the number of blocks in the sequence increases up to 9 as participants respond correctly(see Appendix B). Therefore, Corsi tasks are used to evaluate the visuospatial short-term memory by determining the length of the sequence (Kessels, Zandvoort, Postma, Kappelle, & Haan, 2000). Using PsyToolkit web-based platform, digital versions of Corsi forward task utilized to assess visual memory span of fourth-grade students (Stoet, 2010, 2017).

3.3.4 Working memory battery: Go/No-Go test (GNGT)

The go/ no-go task is an instrument to measure response inhibition to the different stimuli. Response inhibition can be referred to as the ability to withhold a response, and the inability to stop responding shows low response inhibition (Wright, Lipszyc, Dupuis, Thayapararajah, & Schachar, 2014, p. 430). A web-based tool was used to measure the response inhibition of the participants in the current study (Stoet, 2010, 2017). In this task, the participant is expected to press the corresponding key quickly as the go stimuli appear and withhold responding when no-go stimuli appear. Therefore, the number of go trials (20) is more than no-go trials (5) to assess the response inhibition performance when a no-go trial appears.

Analyzing the fourth-grade students' go/no-go task performances, the mean reaction time of the correct trials (MRT) variable was used to measure decision-making, response initiation, and preparedness (Wright et al., 2014). The mean reaction time of correct trials is also used to measure attentional control (Rodríguez-Villagra, Göthe, Oberauer, & Kliegl, 2013). In this study, the MRT of correct trials was calculated to measure the students' attentional control performances. The go-no-go

trials were utilized for the fourth-grade students and the other tasks in the working memory battery (see appendix B).

3.3.5 Mathematical problem-solving test (MPST)

A mathematical problem-solving test was used to assess students' mathematical problem-solving ability. The items in the test were adapted from released items of Trends in International Mathematics and Science Study (TIMMS, 2003, 2007, 2011; Özel, 2021). The test consists of 8 items, and it is prepared to assess problem-solving ability in the following content domains: data, measurement, geometric shapes and measures, and number. According to the problem-solving assessment framework of TIMMS, each item is prepared to include one or more of the attributes determined for the problem-solving process (Özel, 2021).

The items should allow students to

- describe variables and relationships,
- evaluate information from a multi-dimensional perspective,
- rationalize solutions and to present proofs,
- generalize and anticipate feasibility,
- communicate their solutions more than a single word answer,
- connect and embody information (TIMMS, 2006, p.73).

Thus, the MPST instrument included 8 items having one or more of the above attributes. Interpreting students' work and calculating the test scores, the researcher prepared a scoring guide in accordance with the codes provided by TIMMS (see appendix D).

3.3.6 Mathematics exams

In the first semester of school, two mathematics exams were prepared by two classroom teacher, one mathematics teacher and an academic coordinator for validation considerations. The exams were applied to assess students' mathematics success. Each exam consisted of 11 items (see Appendix G), and Cronbach alpha values were calculated from mathematics exam results of all fourth-grade students in the school. Cronbach's alphas were found as .71 and .64, respectively. Therefore, the exams were found to be reliable to use a measurement tool in this study. The exam averages were calculated to obtain MEA as an independent variable of mathematics achievement.

3.3.7 Video-recording based interviews

In this study, semi-structured interviews were conducted as the study aims to reveal number sense strategies in the game environment, and opinions of participants based on certain characteristics of game environment. The semi-structured interview is the most prevalent type of interviews in social sciences and education studies (Brinkmann, 2014; McIntosh & Morse, 2015; Rowley, 2012). Being widely used in educational research, the implementation of semi-structured interview requires systematic thought and plan (Kallio, Pietilä, Johnson, & Kangasniemi, 2016). There is a suggestion that semi structured interviews should be preferred when previous knowledge of research problem exist (Kallio et al., 2016; Kelly, 2010). Thus, a semi-structured interview type was chosen in this study because the preliminary information and categories in the number sense literature were used.

Semi-structured interviews allow interviewees more room to hold knowledge-producing conversations while keeping up the interviewer on the issue

with the aid of interview protocol (Brinkmann, 2014). The interview protocol includes the main topics of the study, and it needs to be prepared to determine interview questions. Before employing the interview, an interview protocol was prepared to guide the interviewer, to cover all questions, and to ask all questions in the same order to the participants (see Appendix I).

Interview protocols are prepared with methodical decisions. Firstly, researcher needs to assure that interview questions in the interview protocol correspond with research questions of the study (Castillo-Montoya, 2016). In this study, interview questions were designed to answer research questions, benefiting from the knowledge of number sense and video game research literature. The main questions and follow-up questions were prepared considering interview protocol to interpret better the phenomena (i.e., opinions and experiences) and integrate transcripts around certain categories (i.e., game flow and learning experiences).

Tomlinson's (1989) research interview strategy, combining hierarchical focusing (i.e., five steps explained below) and contextual focusing (i.e., Piagetian clinical interview), was adopted to prepare interview protocol and interview questions. According to this strategy, the interviews must be conducted according to five dimensions:

1. employing an analysis of the content and the hierarchical structure of the domain in question.
2. deciding focus of research and identifying elements of the topic.
3. preparing a hierarchical agenda of questions, based on these elements, is enlisted open to close framing.
4. as far as possible employing the interview open ended without uttering leading questions. Taking tape-record of the interview.

5. Creating a transcript word for word and analyzing protocols in the tape record. Tomlinson (1989, p.162)

Adopting hierarchical focusing stands for carrying out hierarchical scheme (i.e., asking questions only when required) and giving more importance on openness of interviewee while reducing researcher influence in framing (Tomlinson, 1989, p.162). In the current study, contextual framing was selected, which was Piagetian type of conversation, to examine student thinking related number sense tasks. Five dimensions of hierarchical focusing was used to determine structure of the interview protocol. Additionally, Piagetian clinical interview framework (i.e., contextual focusing) was adopted to discover students' cognitive strategies used in number sense intervention sessions (Tomlinson, 1989).

The content of the study was the number sense development,and focus of the interview was identification of number sense strategies and eliciting students' opinions about the game. Proposing to raise questions from general to specific, the top-down approach of hierarchical focusing was adopted to determine organization of questions. Accordingly, interview questions were arranged from general to the specific and leading questions were avoided not to influence interviewee. In particular, students' ideas and descriptions about the videogame learning activities were asked in the beginning of the interview.

Moreover, arranging conversational interviews, consulting experts, and conducting a pilot study are necessary steps in designing the interview protocol (Castillo-Montoya, 2016). Not to restrict interviewees with leading questions, the interview questions were designed relatively open-ended to allow conversational language with some prompts. The interview protocol was reviewed, leading questions were removed and rearranged according to advisors' suggestions.

Employing an interview requires skill and experience of the interviewer (Rowley, 2012). A pilot study with two students was conducted to evaluate organization of the questions and to get interview experience.

3.4 Data collection procedure

Before conducting the study, the approvals were taken from the sub-Ethics Committee of the Boğaziçi University (see Appendix J). The school principal was informed about the requirements of the study and asked for permission to participate.

The students' families were informed about the study by sending the consent forms and were asked to participate in the research. In addition to obtaining permission from the parents of the students with the Information and Consent Form (see appendix K), the students were explained in detail that the activities they did within the scope of this research would not affect their course grades and that the participation in the research was voluntary.

First, students took the pre-test in one class hour. After one week later, the school was shut down because of Covid-19; therefore, a new plan was devised to apply activities. Activities were completed during four weeks with the personal computers of students. At the end of the treatment, the BNPT post-test was applied for 40 minutes online mathematics lesson. After collecting quantitative data, which were number sense ability results, 6 participants were selected for the interviews in accordance with the following criteria:

- Two students having low learning gains
- Two students having moderate learning gains
- Two students having high learning gains

3.4.1 Treatment

3.4.1.1 Pilot Study

The pilot study was carried out in two stages: designing the game and teaching participants how to play the game. To design the game, the researcher and advisor of the research played the game. They recorded problems regarding game mechanics and the technology. The researcher studied with two fourth grade students who were enrolled in a state school. One of the students had previous experiences with Minecraft, and the other had no experience. Students were played the game and their game experiences were observed and recorded. After evaluating game experiences of the students, the game mechanics were altered second times.

The second stage of the pilot study was conducted with the participants of this study. The purpose of this stage was to teach the Minecraft game. Participants played Minecraft games for six weeks in the following topics: division world, three-dimensional fractions, angles world, the volume of cubes, geometry world, and symmetry. At the beginning of the study, participants were given school emails and passwords and were taught how to log in to their game account. Next, the participants created their game avatar and opened a new virtual world. They learned how to move around the videogame by using a keyboard and mouse. After they learn to move around in the game, students were taught how to open and pick objects from inventory. They picked some objects from the inventory and started to craft.

During two weeks of the pilot study, some of the students had difficulty controlling the mouse. To overcome this difficulty, they worked in pairs to help each other during the tasks of division world and three-dimensional fractions. Unfortunately, after implementing these tasks, the school was temporarily closed for

one week due to the Covid-19 plague. After the one-week holiday, an adaptation plan of implementation of the pilot study was developed.

The students were sent a manual explaining installation and locating the programs, screen recording without audio, and sending the record to the researcher. Three screen recording programs were presented to the participants according to computer compatibility and computer specs. Students taught three-screen recording methods individually, and one of the most convenient methods was determined according to the computer specs of participants. These three programs were as follows: Open Broadcaster Software (OBS), Game Bar software program in Windows 10, and online screen recorder. Online screen recorder preferred the other programs as the programs generate data in small size compared with OBS and Game Bar.

In the following four weeks, participants were sent virtual world mathematical tasks: angles world, the volume of cubes, geometry world, and symmetry. The students were shown how to upload a screen recording file to a Drive file opened by their name. They uploaded video records of the projects to the Drive file during the pilot study.

3.4.1.2 Number sense tasks with Minecraft sandbox game

Due to the continuing conditions of the Covid-19 pandemic, the number sense tasks were implemented in the personal computers of students on account of the epidemic. However, after the pilot study, the participants became familiar with Minecraft and data collection procedures. Therefore, consequences of epidemic were attempted to minimize.

There were 10 tasks which are (1) reporting ocean pollution, (2) waste detection in the dark, (3) chemical wastes in the water, (4) floating plastics in the ocean, (5) metal waste, (6) waste of masks, gloves, and bottles, (7) global warming number line estimation, (8) drought in the farm, (9) barren land, and (10) solution to deforestation (see Table 1). The first six activities were designed to improve subitizing performances, and 25 minutes of playtime limit were set. The counting games were designed in survival mode to constraint counting time of participants as counting was time dependent. The tasks required students to dive and count the objects in three seconds then select correct answer. If student stayed in the water more than three seconds a lot of puffer fish summoned and poisoned the child. Therefore, they are obliged to get out of water to decrease their response times. The counting tasks can be referred as action video games in this regard. After designing the counting game, the researcher and advisors played the game. Lastly, the game was played by two students who were not participants of this study.

The last four activities were designed to improve the mental number line estimations of the participants, and 40 minutes of playtime were determined. Therefore, total activity time of number sense tasks was planned as 310 minutes, 150 minutes of subitizing tasks, and 160 minutes of number line estimation tasks. All game activities were played individually. Students were told to record their computer screens during the activity times. They were told to exclude audio during the recording.

Table 1. Details of Number Sense Activities in Virtual Game Environment

Week	Name of the Activities	Number Sense area and subareas	Objective	Duration	
1st Week	1- Reporting Ocean Pollution 2- Waste Detection in the Dark 3- Chemical wastes in water	Approximate Number System – Subitizing Canonic Dot Counting (CDC) Random Dot Counting (RDC)	To estimate approximate number of dot arrays	25+ 25 + 25 minutes	(Goukon, 2016; Ashkenazi et al., 2013; Starkey & McCandliss, 2014)
2nd Week	4- Floating Plastics in the Ocean 5- Metal Waste 6- Waste of masks, gloves, and bottles	Approximate Number System – Subitizing Canonic Dot Counting (CDC) Random Dot Counting (RDC)	To estimate approximate number of dot arrays	25 + 25 + 25 minutes	(Goukon, 2016; Ashkenazi et al., 2013; Starkey & McCandliss, 2014)
3rd Week	7- Global Warming Number Line Estimation 8- Drought in the Farm	Mental number line (MNL10) (MNL100)	To improve number line estimation accuracy in number lines between 0-10, 0-100	40 + 40 minutes	(Booth & Siegler, 2006)
4th Week	9- Barren Land 10- Solution to Deforestation	Mental number line (MNL1000)	To improve number line estimation accuracy in number lines between 0-1000	40 + 40 minutes	(Booth & Siegler, 2006)

3.4.1.3 Subitizing tasks

The objective of subitizing tasks was to improve subitizing performance of fourth-grade students. At the beginning of each episode, the task assignment was given by agents in the video game, and students were told to determine the number of objects

buried in the deep ocean of Minecraft world (see Figure 3). During the subitizing tasks, students played the game in the survival mode individually. Subitizing activities were designed in the survival mode to restrict the time of the counting. The dot arrangements in the activities were determined in accordance with the study of Goukon (see Appendix E). ANS tasks were placed to evaluate students' strategies on different counting tasks, to diversify the subitizing tasks.

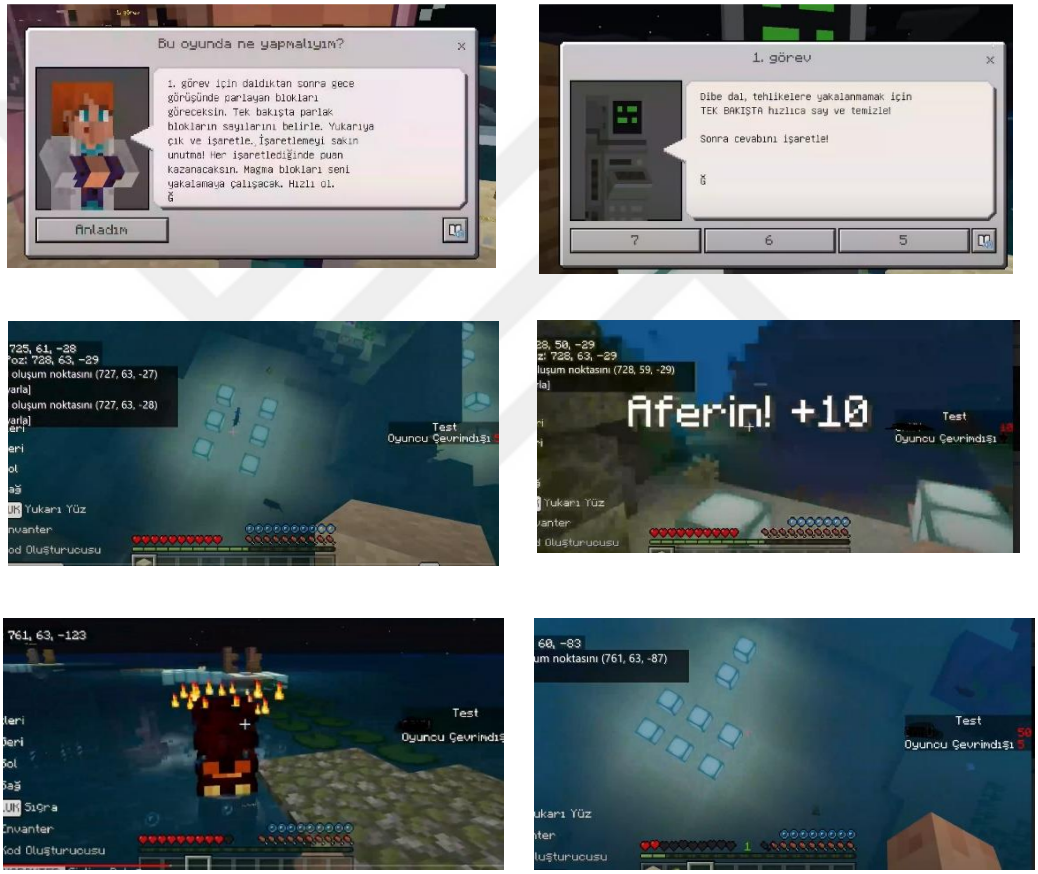


Figure 3. Screenshots of a subitizing task

3.4.1.4 Number-line tasks

Number line tasks were designed to improve number line estimations of fourth-grade students. The activities included the ten-number line, the hundred number line, and the thousand number line. Each activity was designed around a narration to save the

environment. The ten-number line task was required participants to determine the amount of melting ice to report global warming (see Figure 4). The hundred number line task required students to dig the soil so as to find water for farmers (see Figure 5). The thousand number line task required students to locate the fertile soil which was hidden underneath the true location of the number (see Figure 6). Unlike subitizing activities, the number line tasks were designed in the game's creative mode and required students to do flying and jumping movements. The study of Booth and Siegler (2006) was taken as a framework when determining the numbers to be included in the number line task (see Appendix E).

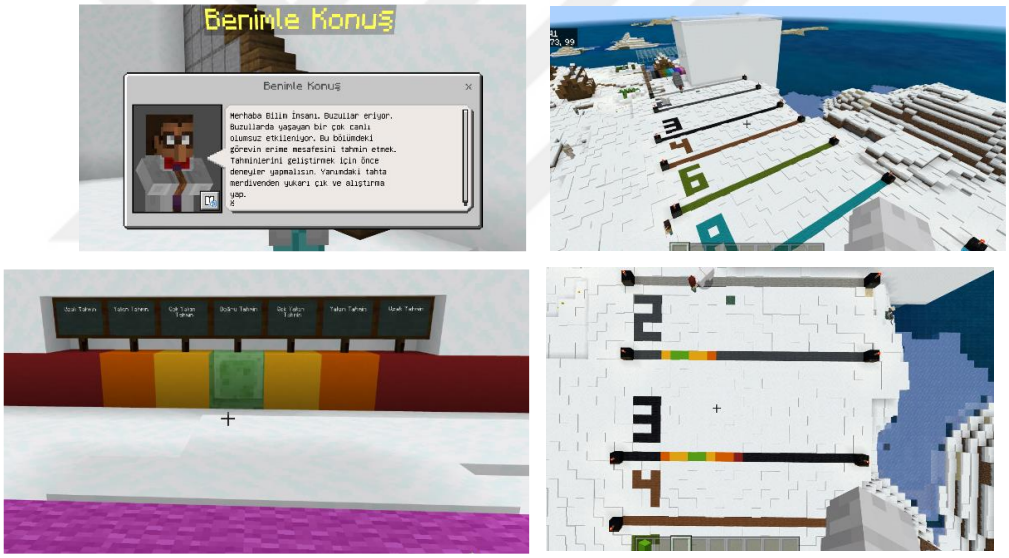


Figure 4. Screen shots of the 0-10 number line tasks

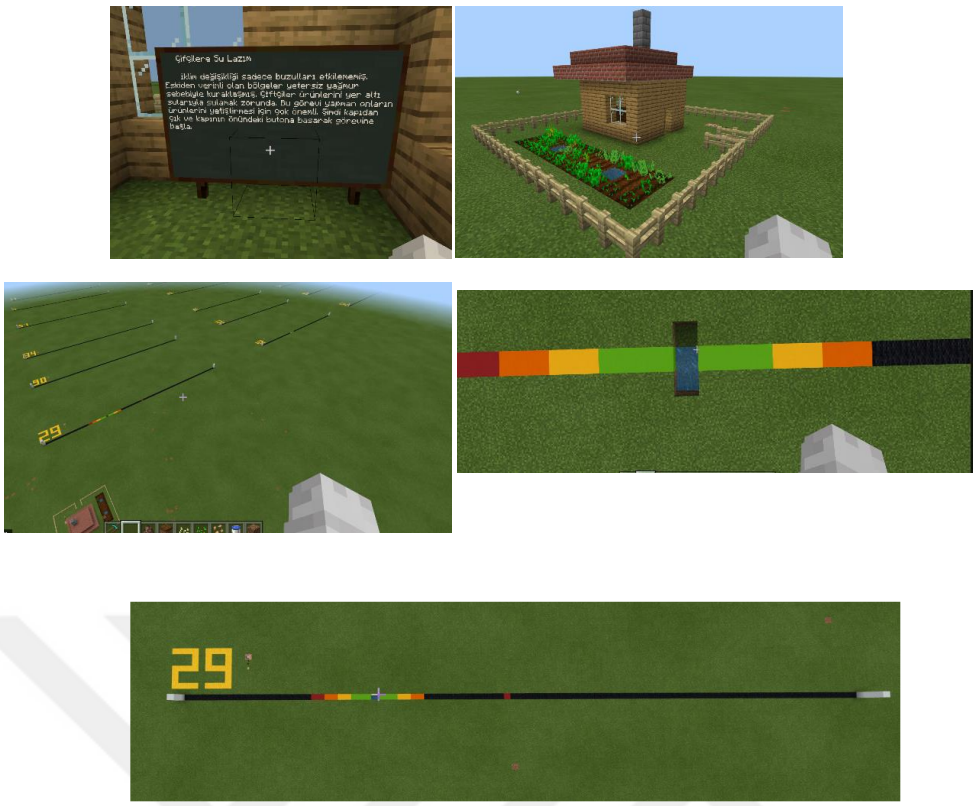


Figure 5. Screen shots of the 0-100 number line tasks



Figure 6. Screen shots of the 0-1000 number line tasks

3.4.1.5 Design of Minecraft number sense tasks

The subitizing and counting tasks were designed in survival mode; therefore, six of the maps were action games in this regard. The tasks required students to dive and to go out quickly. Therefore, a practice section was created before beginning the tasks.

Game and player interactions were primarily provided by coding non-player characters (NPCs) and the scoreboard. Rewards were given as points. When students correctly answered the question, they gained 10 points, which immediately appeared on the screen and score board (see Figure 7). Additionally, if the play time exceeded 25 minutes, a text appeared on the screen indicating the time was over.



Figure 7. Creating feedbacks and scoreboard

The challenges of the subitizing and counting tasks, on the other hand, were created according to the players' location. That is, a flock of power fish were summoned when players stayed in the water for more than 3 seconds (see Figure 8). If players come back to the NPC to answer the question, the summon code was deactivated. Therefore, limiting counting time by summoning a flock of pufferfish was the gist of the counting tasks.



Figure 8. Summoning code of a flock of puffer fish

Moreover, effective navigation was one of the most important elements of game design. Navigation was settled by creating invisible boundaries, check points, and numbering NPCs. First, invisible boundaries were placed after creating the first map, therefore; players were not allowed to walk around unpurposefully. Second, check points were created by coding the last location of players so that they did not start from the beginning when they die (see Figure 9).



Figure 9. Check points and number of NPCs.

The number line tasks were designed in creative mode, and each number line task required players to fly, aim and jump. Therefore, a practice section was created so that players could easily jump to the aimed location (see Figure 10). The number line tasks were different from the counting tasks, making estimations rather than

finding exact values. Therefore, feedback was provided by placing different color of blocks.

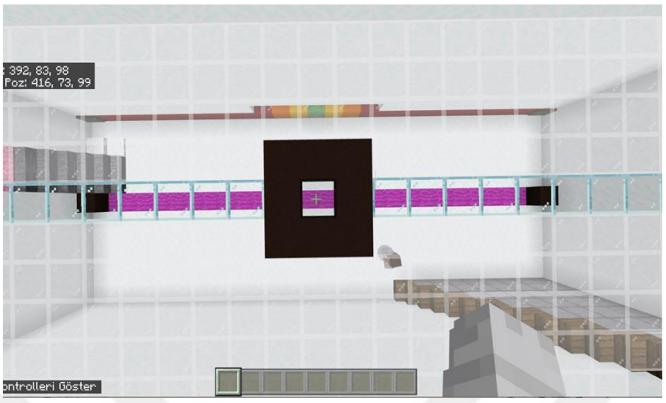


Figure 10. Practice section before beginning number line tasks

The meaning of color was explained at the beginning of the game. Green blocks, yellow blocks, orange blocks, and red blocks were constructed, and finding these objects implied very close estimation, close estimation, far estimation, and very far estimation, respectively (see Figure 11). For instance, if a player estimated 50 on a hundred number line, 3 and a half green blocks were constructed at both ends of 50, where the estimate error was equal to 7%.



Figure 11. Color blocks indicating level of estimation

The estimate error percentages were determined in accordance with the results obtained in the study by Booth and Siegler (2006). Moreover, if the player

jumped on a block where the estimation error was bigger than 7%, then a yellow block appeared under the number line. If a player jumped far away from the exact location, then red blocks appeared.

After finding green blocks, players were required to dig green blocks to find the chest placed under the exact point on ten number line. Players were expected to collect nine diamonds in the chests at the end of the ten-number line map. These diamonds were used to create a music box at the end of the game (see Figure 12).



Figure 12. Rewards of ten number line tasks

Furthermore, hundred number line tasks required students to find water resources as rewards. Water resources were placed only under green blocks, and when players dig to the green block, they found water resources for farmers. Therefore, farmers were able to irrigate the plants. The thousand number line tasks, on the other hand, required students to find fertile soil by digging under the green blocks. After finding fertile soil, players were expected to plant a tree to prevent deforestation.

Providing effective navigation in hundred and thousand number line maps was one of the most challenging parts. As the hundred and thousand number lines were quite long, they were separately constructed so that players were not distracted by irrelevant number lines. Therefore, teleportation buttons were coded to prevent time loss and wandering around the map (see Figure 13). The buttons teleported players to the next number line after finding the correct location and planting the tree.



Figure 13. An example of teleportation button in thousand game

To conclude, the narration of the number sense tasks was designed around a protagonist who was expected to save the environment. The rewards, feedbacks and challenges were carefully designed to ensure consistency between maps.

3.5 Data analysis

3.5.1 Quantitative data analysis

The quantitative data analysis included two primary processes: data cleaning and analysis of the data with SPSS. First, variables regarding the subcomponents of NS (i.e., exact enumeration, symbolic number comparison, and number line estimation) were organized separately in the SPSS tool, and the scores of NS subcomponents and total scores of NS pre-test and post-test were calculated. Second, variables regarding the executive functions and working memory capacity (i.e., inhibitory control, visuospatial short-term memory, attention) were organized for each participant, and scores were calculated. Third, students' mathematical problem-solving test scores were calculated by a problem-solving rubric (see Appendix D). Last, Cronbach's alpha values and averages of mathematics exam test scores were calculated.

After data cleaning, data analysis was processed to answer research questions. To analyze the data, descriptive and inferential statistics were used. Additionally, regression analysis and multiple regression analysis were held to calculate relationships between variables. In the below paragraphs, the analysis procedure of each question is explained separately.

To select the appropriate statistical method in answering the first research question (i.e., parametric or non-parametric testing), normality tests were utilized for NS pre-test and post-test total scores. Pre-test data distribution was found as skewed, while post-test data distribution was normal. To fit the data into the normal

distribution model, logarithmic data transformations were applied. As the pre-test and post-test data were negatively skewed, the logarithmic transformation was conducted in SPSS by reflecting the pre-test data and post-test data with the following formulas Log 10 (the maximum value of pre-test + 1- pre-test data) and Log 10 (the maximum value of post-test + 1- post-test data). After logarithmic transformations, the data distributions were normal, and paired-samples t-test were utilized. According to the statistical analysis, the effect size of the analysis was very small, and instead of parametric tests, it was decided to use a non-parametric test which was Wilcoxon signed-rank test.

Hierarchical multiple regression analysis was conducted to answer the following research questions.

Research question 2a: How much does working memory capacity, problem solving skills and mathematics achievement of fourth grade students explain variance in RDC performances?

Research question 3a: To what extent do working memory capacity, school mathematics exam grades and mathematical problem-solving abilities of fourth grade students explain variance in MNL-10 scores?

Research question 3b: To what extent do working memory capacity, school mathematics exam grades and mathematical problem-solving abilities of fourth grade students explain variance in MNL-100 scores?

Research question 3c: To what extent do working memory capacity, school mathematics exam grades and mathematical problem-solving abilities of fourth grade students explain variance in MNL-1000 scores?

Before the analysis, the linearity, normally distributed dependent variable, multicollinearity, and heteroscedasticity assumptions of multiple linear regression

were tested. First, linearity assumption was tested by sketching scatter plots. Then, the Shapiro Wilk test was employed to test whether dependent variables were normally distributed or not. Multicollinearity assumption was tested by calculating correlations between independent variables, and afterward, a correlation matrix was examined. Last, the heteroscedasticity assumption was tested by sketching residual plots.

3.5.2 Qualitative data analysis

Qualitative analysis presents thematic data by using categorical and contextualizing strategies (Teddlie & Tashakkori, 2009). In explanatory sequential design, researcher can select participants of qualitative phase purposefully. This enables to the exploration of unexpected results in the quantitative phase. The interview questions were asked to 6 participants who were purposefully selected.

Qualitative data analysis included two steps determining apriori categories and utilizing the constant comparative method to analyze qualitative data. First, the literature reviewed under the categories of instructional game design as well as the number sense strategies and apriori codes were determined according to those categories. Second, the constant comparative method is utilized to analyze qualitative data. Glaser (1965, p.439) subsumed the levels of constant comparative method as (1) comparison of incidents with already coded incidents that fit into the same category, (2) developing unified theories by integration of distinct categories and their properties, (3) processing focused analysis and considerate coding of incidents by delimiting the theory, and (4) writing the theory. The first analysist followed the stages of the constant comparative method attentively by creating unified yet authentic categories.

As stated earlier, six cases were selected to explain the quantitative results. First, two analysts came together and coded the incidents of one interview according to apriori codes in the codebook. Then, they deleted three codes and modified one of the codes in the codebook. In the end, 171 codes were created for the first interview. The first analyst analyzed the remaining eight interviews, and the second analyst analyzed one out of eight interviews alone. After that, the two analysts came together to compare the interview codes that were analyzed separately. After the comparison, 8 codes were deleted, and 4 codes are changed among the 92 codes. As Glaser (1965) suggested, the two of the analysts integrated the categories and properties of interviews to condense into main theories in the investigation of the phenomenon. Apriori categories, main themes, and sample code texts were presented in appendix H. In the current research, qualitative findings will be represented as multiple cases.

CHAPTER 4

RESULTS

In this chapter, the results of the analyses were reported to answer four research questions. The descriptive and inferential statistics were used to demonstrate the results.

4.1 Descriptive Statistics

Kolmogorov-Smirnov and Shapiro Wilk normality tests were carried out to test whether the total pretest and the total posttest NS scores were normally distributed (see Table 2). Accordingly, the pretest scores were not normally distributed ($p <$ .001) and skewed to the left (skewness = -1.99, kurtosis = 3.55), while posttest data did not violate normality assumptions (skewness = -.51, kurtosis = -.32) (p = .20). Therefore, a non-parametric test, the Wilcoxon signed-rank test, was used to answer research question 1.

As stated previously, BNPT instrument included six tests, and results obtained from each test was analyzed separately to measure different subcomponents of NS (Olkun et al., 2020; Olkun & Akkurt-Denizli, 2015). Therefore, the differences between pretest and posttest scores and response times in random dot counting (RDC), canonic dot counting (CDC), and symbolic number comparison (SNC) were analyzed with the Wilcoxon-signed rank test. In addition, response time differences between RDC, CDC, and SNC pretest and posttest were analyzed by calculating Inverse Efficiency Scores (IES).

Kolmogorov-Smirnov tests were employed to check normality assumptions of inverse efficiency scores. The inverse efficiency scores of random dot counting pretest was normally distributed, (skewness = -.31, kurtosis = -.85) (p = .200), and

random dot counting posttest was normally distributed, (skewness = .90, kurtosis = -.04) (p = .200). The inverse efficiency scores of canonic dot counting pretest was normally distributed, (skewness = -.54, kurtosis = -.53) (p = .200), and canonic dot counting posttest was normally distributed, (skewness = .93, kurtosis = 1.43) (p = .200). The inverse efficiency scores of symbolic number comparison pretest was not normally distributed, (skewness = 1.42, kurtosis = 3.89) (p = .08), and symbolic number comparison posttest was normally distributed, (skewness = .79, kurtosis = -.54) (p = .03). Therefore, Wilcoxon signed-ranked test was utilized to test the statistical difference between pretest and posttest response time scores of RDC, CDC, and SNC.

Table 2. Descriptive Statistics of Pre-Posttest Scores and Inverse Efficiency Scores

	N	Skewness	Kurtosis	Min	Max	Mean	Median	*SD*
Pretest	21	-1.99	3.55	276	344	326.81	332	18.06
Posttest	21	-.51	.32	317	349	339.22	13	5.94
RDC_pre_score	21	-1.79	2.54	15	21	19.91	21	1.76
RDC_post_score	21	-.53	-.67	18	21	20.05	20	.92
RDC_IES_pre	21	-.31	-.85	43	101	77.72	78	16.34
RDC_IES_post	21	.90	-.04	56	115	75.9	71	17
CDC_pre_score	21	-.53	-.67	18	21	20.05	20	.92
CDC_post_score	21	-.76	-1.58	20	21	20.67	21	.48
CDC_IES_pre	21	-.54	-.53	42.10	93	62.95	62.04	13.54
CDC_IES_post	21	.93	1.43	41	81.90	62.16	61.95	15.78
SNC_pre_score	21	3.25	11.89	14	21	20.19	21	1.60
SNC_post_score	21	-2.88	7.56	12	21	20.10	21	2.43
SNC_IES_pre	21	1.42	3.89	27	57.05	36.47	36.05	6.57
SNC_IES_post	21	.79	-.54	23	55	34.28	32	9.55

Note. RDC_pre_score indicates random-dot counting scores in pretest, CDC_post_score indicates canonic dot counting scores in the posttest, SNC_pre_score indicates symbolic number comparison scores in pretest, RDC_IES_pre, and CDC_IES_post indicate scores of response time in pretest and posttest.

Kolmogorov-Smirnov test was employed, and normality assumptions were not satisfied for all number line (MNL10, MNL100, MNL1000) pretest and posttest

scores ($p < .05$). Thus, the pretest and posttest differences between mental number line scores were calculated by Wilcoxon signed ranked test (see Table 3).

Table 3. Descriptive Statistics of Mental Number Line Scores

	N	Skewness	Kurtosis	Min	Max	Mean	Median	*SD*
MNL10_pre_score	21	-1.86	3.15	73	96	89.33	91	6.07
MNL10_post_score	21	-1.97	6.14	85	94	92	92	2.05
MNL100_pre_score	21	-2.59	6.40	72	94	90.14	92	5.65
MNL100_post_score	21	-1.09	.63	86	97	92.43	94	3
MNL1000_pre_score	21	-1.23	.64	70	95	87.19	89	7.37
MNL1000_post_score	21	-1.43	1.48	79	96	90.57	93	4.61

Note. MNL10_pre_score represents ten number line scores in pretest, MNL100_post_score represents hundred number line scores in the posttest, MNL1000_pre_score represents thousand number line scores in the pretest.

4.2 Effect of video-game number sense tasks on the number sense gains

Research question 1: Is there a significant difference between pretest and posttest number sense scores of fourth-grade students who completed number sense tasks in the virtual game environment?

As shown in Table 4, Wilcoxon signed-rank test results indicated a statistically significant difference between pretest and posttest scores, $z = -2.58$, $p = .010$. That is, the posttest scores were significantly higher than the pretest scores, and the effect size of this difference was moderate ($r^2 = .56$).

Table 4. Wilcoxon Signed-Rank Test for Pre-test and Post-test

			N	Mean Rank	Sum of Ranks
Pretest Score-Posttest Score	Ranks	Negative	14a	12.43	174.00
		Positive Ranks	6b	6.00	36.00
		Ties	1c		
		Total	21		

a. Posttest Score < Pretest Score
b. Posttest Score > Pretest Score
c. Posttest Score = Pretest Score

Note. Pretest indicates the sum of pretest scores of all sections, namely, RDC, CDC, SNC, MNL10, MNL100, and MNL1000. Posttest indicates the sum of posttest scores of all sections, namely, RDC, CDC, SNC, MNL10, MNL100, and MNL1000.

Wilcoxen signed-ranked test was employed to test the difference between pretest and posttest inverse efficiency scores in RDC, CDC, and SNC tasks. There was no significant difference in the RDC pretest inverse efficiency scores and RDC posttest inverse efficiency scores $z = -.85$, $p = .39$ There was no significant difference in the CDC pretest inverse efficiency scores and CDC posttest inverse efficiency scores, $z = -82$, $p = .41$. There were no significant differences in the SNC pretest inverse efficiency scores and SNC posttest inverse efficiency scores, $z = -1.443$, $p = .15$.

Additionally, the number line pretest-posttest scores were analyzed with Wilcoxon signed-rank test (see Table 5).

Table 5. Summary of Wilcoxon Signed Ranked Test for Number Line Scores.

		N	Mean Rank	Sum of Ranks
MNL10(pre)-MNL10(post)	Negative Ranks	10[a]	11.55	115.50
	Positive Ranks	7[b]	5.36	37.50
	Ties	4[c]		
	Total	21		
MNL100(pre)-MNL100(post)	Negative Ranks	13[d]	9.15	119.00
	Positive Ranks	4[e]	8.50	34.00
	Ties	4[f]		
	Total	21		
MNL1000(pre)-MNL1000(post)	Negative Ranks	14[g]	11.96	167.50
	Positive Ranks	6[h]	7.08	42.50
	Ties	1[i]		
	Total	21		

a. MNL10(pre) < MNL10 (post)
b. MNL10(pre) > MNL10 (post)
c. MNL10(pre) = MNL10 (post)
d. MNL100(pre) < MNL100 (post)
e. MNL100(pre) > MNL100 (post)
f. MNL100(pre) = MNL100 (post)
g. MNL1000(pre) < MNL1000(post)
h. MNL1000(pre) > MNL1000 (post)
i. MNL1000(pre) = MNL1000(post)

Note. MNL10(pre) represents ten number line scores in the pretest, MNL100(post) represents hundred number line scores in the posttest, MNL1000(pre) represents thousand number line scores in the pretest.

The results have shown that there was a statistically significant difference between pretest and posttest scores in hundred number line (z = -2.03, r^2 = .44, p = .043), and in thousand number line (z = -2.34, r^2 = .51, p = .019). There was no significant difference between pretest and posttest scores in ten number line (z = -1.86, r^2 = .41, p = .063). hundred number line scores and thousand number line scores were significantly higher than the pretest with moderate effect sizes. The video game instruction provided students to improve their precisions in hundred number line and thousand number line estimation tasks.

4.3 Regression Analysis

Multiple regression analysis was utilized to approach the second and the third research questions, and descriptive statistics of variables were calculated (see Table 6). The normality, linearity, reliability, and homoscedasticity assumptions of multiple regression were tested by statistical analysis and visual inspection of probability-probability plots and residual plots. According to Kolmogrow Simirnow normality test results, all variables in Table 2 were normally distributed except number line scores. The non-normally distributed variables were transformed by using box-cox transformations. Therefore, the normality assumption was satisfied.

Table 6. Descriptive Statistics of Regression Variables

	Mean	*SD*	*N*
RDC_IES_total_performances	153.62	27.41	21
CDC_IES_total_performances	125.11	25.65	21
SNC_IES_total_performances	70.75	14.43	21
MNL10 total score	181.33	6.95	21
Dif_MNL10	2.67	5.81	21
MNL100 total score	182.57	7.39	21
Dif_MNL100	2.29	5.22	21
MNL1000 total score	177.76	10.64	21
Dif_MNL1000	3.38	6.16	21
Mathematics exam averages	87.46	8.23	21
Problem-solving test scores	138.29	55.65	21
Corsi span	5.29	.96	21
Stroop reduction percentage	-20.14 %	14.24 %	21
Go-no-Go mean reaction time (GNG)	452.89	108.94	21

a. RDC, CDC, and SNC IES indicate the sum of pretest and posttest IES scores.
b. MNL10 total scores represent the sum of pretest and posttest scores.
c. Dif_MNL10 indicates differences between ten number line pretest and ten number line posttest.
d. Stroop reduction percentage represents the percent of delay in response time when incongruent stimuli present.
e. Corsi span, Go-no-Go, and Stroop reduction percentages were measures of working memory capacity.

4.3.1 Correlations

Bivariate correlation among outcome variables and predictor variables was shown in Table 7. Results indicated that random dot counting (RDC) response time was significantly correlated with mathematics exam averages (MEA) ($r_{RDC\text{-}MEA} = -.44$, $p = .044$). Thus, students who had smaller response time scores in random-dot counting tasks tended to perform better in the curriculum-based mathematics exam. In addition, the correlation between random-dot counting performance and symbolic number comparison (SNC) performance was .70 ($p < .001$), which implied that shorter random-dot counting response times were promising for response time scores of symbolic number comparison.

The canonic dot counting performances were not significantly correlated with independent variables; however, there was a statistically significant correlation between random dot-counting performances and canonical dot-count counting performances ($r_{RDC\text{-}CDC} = .66$, $p = .001$). Thus, students who had high performances in canonical tasks were more likely to perform better in RDC tasks, requiring a higher degree of subitizing skill.

The ten number line scores significantly correlated with hundred number line scores ($r_{MNL10\text{-}MNL100} = .66$, $p = .001$) and thousand number line scores ($r_{MNL10\text{-}MNL1000} = .55$, $p = .01$). However, the effect size of the correlation between hundred number line and thousand number line scores was the highest among the scores of number line tasks ($r_{MNL100\text{-}MNL1000} = .77$, $p < .001$).

In addition, visual-spatial working memory performances and hundred number line scores were positively correlated significantly with small effect size ($r_{MNL100\text{-}Corsi_S} = .44$, $p = .048$). Visual-spatial working memory span and thousand number line scores were correlated significantly with moderate effect size ($r_{MNL1000\text{-}}$

$_{Corsi_S}$ = .58, p = .006). As presented in Table 3, students had the lowest scores in the thousand number line (M = 177.76, SD = 10.64). Therefore, individual differences in visuospatial working memory capacity became more distinctive for the thousand number line, namely, the tasks which required a higher level of cognitive effort.

The thousand number line performances also significantly correlated with mathematics exam averages ($r_{MNL1000\text{-}MEA}$ = .60, p = .004) and problem-solving test scores ($r_{MNL1000\text{-}PSTS}$ = .44, p = .048), which implied that students with higher mathematics exam averages and problem-solving test scores performed better in thousand number line tasks. Moreover, pretest-posttest differences in thousand number line task significantly correlated with mathematics exam averages ($r_{DIF_MNL1000\text{-}MEA}$ = .-48, p = .027). This result implied that students with lower mathematics exam averages benefitted the most from video game instruction.

Table 7. Bivariate Correlations

	Dot Enumeration Response Time Scores					Number Line Performances						Mathematics Achievement and Problem Solving		Working Memory Performances		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1. Total_IES_RDC																
2. Dif_IES_RDC	.04															
3. Total_IES_CDC	.66**	-.02														
4. Dif_IES_CDC	.46*	.42	.18													
5. Total_IES_SNC	.70**	.25	.45*	.66**												
6. MNL10 total score	-.29	.28	-.49*	.02	-.06											
7. DifMNL10	.33	-.21	.45*	-.21	-.09	-.81**										
8. MNL100 total score	-.22	.12	-.44*	.14	.04	.66**	-.74**									
9. DifMNL100	.15	-.37	.30	-.35	-.24	-.68**	.76**	-.60**								
10. MNL1000 total score	-.32	-.20	-.36	-.18	-.13	.55*	-.63**	.77**	-.49*							
11. DifMNL1000	.09	-.21	.11	-.03	-.13	-.70**	.75**	-.40	.62**	-.51*						
12. MEA	-.44*	.01	-.37	.03	-.19	.41	-.59**	.34	-.31	.60**	-.48*					
13. PSTS	.12	.03	.03	.24	.04	.14	-.23	.41	-.07	.44*	-.05	.44*				
14. Corsi span	-.49*	-.11	-.32	-.36	-.16	.35	-.29	.44*	-.39	.58**	-.15	.22	-.07			
15. SRP	-.23	.03	-.28	-.15	-.32	-.21	.29	-.31	-.08	-.22	.23	-.22	-.35	-.11		
16. GNG mean reaction time	.24	-.26	.36	.04	.16	-.00	.01	-.24	.14	.07	-.26	.28	-.15	-.01	-.37	

Note. * indicates $p < .05$. ** indicates $p < .01$

a. Total_IES_RDC, Total_IES_CDC and Total_IES_SNC were the sums of pretest and posttest response time performances.
b. Dif_RDC and Dif_CDC stand for RDC and CDC response time differences, measured by subtracting posttest performances from pretest performances.
c. DifMNL10, DifMNL100 and DifMNL1000 stand for pretets and posttest differences in number line scores.

4.3.2. Research question 2a

How much does working memory capacity, mathematics achievement, and problem-solving skills of fourth-grade students explain variance in random-dot counting performances?

To approach research question 2a, hierarchical linear regression was performed to predict random dot counting response times (RDC__IES) from working memory performances, mathematics achievement, and mathematical problem-solving. The ANOVA results of hierarchical regression analysis were presented in Table 8.

Table 8. ANOVA Results of Random Dot Counting Scores

Model		Sum of Squares	df	*MS*	*F*	*p*
1	Regression	1185.72	2	592.86	.77	.477[b]
	Residual	13837.94	18	768.77		
	Total	15023.66	20			
2	Regression	5121.49	3	1707.16	2.93	.063[c]
	Residual	9902.17	17	582.48		
	Total	15023.66	20			
3	Regression	8199.40	4	2049.85	4.81	.010[d]
	Residual	6824.26	16	426.52		
	Total	15023.66	20			
4	Regression	9922.10	5	1984.42	5.84	.003[e]
	Residual	5101.56	15	340.10		
	Total	15023.66	20			

a. Predictors: (Constant), GNG_MRT, SRP
b. Predictors: (Constant), GNG_MRT, SRP, Corsi_S
c. Predictors: (Constant), GNG_MRT, SRP, Corsi_S, MEA
d. Predictors: (Constant), GNG_MRT, SRP, Corsi_S, MEA, PSTS
e. Dependent Variable: RDC performance

The control variables were inhibitory control (SRP), and attention (GNG_MRT) analyzed for the first block. According to the results of the hierarchical regression of the first block, the model was not statistically significant; therefore, random dot counting performance was not explained by inhibitory control performances (see Table 9).

Table 9. Results of Multiple Regression Model Fit Predicting Random Dot Counting Performances

Predictor	Model 1	Model 2	Model 3	Model 4
Constant	.28 (26.35)	.58* (38.07)	.74* (52.50)	.81* (46.98)
Inhibitory control	-.16 (.47)	-.23 (.41)	-.28 (.35)	-.07 (.36)
Attention	.18 (.06)	.15 (.05)	.27 (.05)	.48 (.05)
Visuospatial memory		-.52 (5.68)	-.41 (4.99)	-.30 (4.68)
Mathematics achievement			-.49 (.61)	-.74 (.65)
Problem-solving ability				.47 (.10)
R^2	7.9	34.1	54.6	66

Cell entries are estimated regression coefficients and standard errors *p < .05.

Note. Dependent Variable: random dot counting performance

The third predictor variable, visuospatial memory, was included in the second block analysis, and the model was statistically significant (see Table 8) (p = .01). As shown in Table 9, R^2 change value revealed that visuospatial working memory performances explain 26.2 % of random dot enumeration ability variance (p = .023). In addition, from first block analysis to second block analysis, the standard errors (SE_β) of the inhibitory control decreased, and the correlation coefficient (β) increased. The model results indicated that students who had lower inhibitory control performances tended to spend more time in random-dot counting tasks, which resulted in lower random-dot counting performance. Additionally, students with shorter visuospatial memory span had a longer response time in the random-dot counting task.

The third model analysis was included the mathematics exam averages variable, and the model was statistically significant (p = .010). As shown in Table 9, mathematics exam averages changed the R^2 value from 34.1 to 54.6 (p = .016);

therefore, mathematics achievement explained 20.5% variances in random-dot counting performances. In this model, correlation coefficients of attention and inhibitory control variables increased. If random-dot counting response time could increase one standard deviation, it would result in .28 standard deviations decrease in inhibitory control performance. Similarly, if random-dot counting response times could increase one standard deviation, response times in the attention task would increase .27 standard deviations.

The fourth model summary, demonstrated in Table 9, indicated that the *R*-value was .81; however, problem-solving test scores were positively correlated with random-dot counting inverse efficiency scores. According to this result, the less competent students in dot enumeration had higher scores in problem-solving tests. Therefore, the third model was chosen to explain variances in random-dot counting performances. To conclude, 54.6 % variance in random-dot counting performances was explained by inhibitory control, attention, working memory capacity, and mathematics achievement (F (4, 16) = 4.81, p = .016).

4.3.3 Research question 2b

How much does working memory capacity, mathematics achievement, and problem-solving skills of fourth-grade students explain variance in canonical dot counting performances?

A hierarchical regression analysis was conducted to explain variances in canonical dot counting performances by working memory capacity, mathematics achievement, and problem-solving abilities. The ANOVA results were included in Table 10.

Table 10. ANOVA Results of Canonic Dot Counting Scores

Model		Sum of Squares	df	Mean Square	*F*	*p*
1	Regression	2001.38	2	1000.69	1.62	.226[b]
	Residual	11152.71	18	619.59		
	Total	13154.08	20			
2	Regression	3460.69	3	1153.56	2.02	.149[c]
	Residual	9693.39	17	570.20		
	Total	13154.08	20			
3	Regression	6075.99	4	1519.00	3.43	.033[d]
	Residual	7078.09	16	442.38		
	Total	13154.08	20			
4	Regression	7007.14	5	1401.43	3.42	.029[e]
	Residual	6146.94	15	409.80		
	Total	13154.08	20			

a. Predictors: (Constant), GNG_MRT, SRP
b. Predictors: (Constant), GNG_MRT, SRP, Corsi_S
c. Predictors: (Constant), GNG_MRT, SRP, Corsi_S, MEA
d. Predictors: (Constant), GNG_MRT, SRP, Corsi_S, MEA, PSTS
e. Dependent Variable: CDC performance

The working memory components, i.e., inhibitory control (SRP) and attention (GNG_MRT), were included as control variables in the first block analysis (see Table 11). The results indicated that working memory performances were not statistically significant to explain variances in canonic dot counting performances ($p > .05$).

Table 11. Results of Multiple Regression Model Fit Predicting Canonical Dot Counting Performances

Predictor	Model 1	Model 2	Model 3	Model 4
Constant	.39 (23.66)	.51 (37.67)	.68* (53.46)	.73 (51.57)
Inhibitory control	-.17 (.42)	-.21 (.41)	-.26 (.35)	-.11 (.36)
Attention	.29 (.06)	.27 (.05)	.39 (.05)	.56 (.05)
Visuospatial memory		-.34 (5.62)	-.23 (5.08)	-.14 (5.14)
Mathematics achievement			-.48 (.62)	-.66 (.72)
Problem solving ability				.37 (.11)
R^2	15.2	26.3	46.6	66

Cell entries are estimated regression coefficients and standard errors *p < .05.

The visuospatial working memory performances (Corsi_S) were included in the second block of the regression model. The regression analysis revealed that working memory performances did not explain canonical dot counting performances (p = .135).

In the third block analysis, mathematics exam average was included as a predictor variable, and the regression model was statistically significant (F (4, 16) = 3.43, p = .023, with $R^2 = .46$. However, the fourth block of analysis was not found to be significant and standard errors increased. Therefore, problem-solving scores were excluded from the model, and model 3 was chosen to answer the research question.

To conclude, hierarchical regression analysis revealed that R-value was .68, and 46.6 % of CDC performance variances were explained by working memory performances and mathematics exam averages (see Table 11). Thus, one standard increase in canonic dot counting response times resulted in a .26 standard decrease in inhibitory control performances and a .23 decrease in visuospatial memory span. Similarly, one standard deviation increase in canonical dot-counting response times would result in a .34 increase in attention tasks.

4.3.4 Research question 3a

To what extent do working memory capacity, school mathematics exam grades, and mathematical problem-solving abilities of fourth-grade students explain variance in the ten number line gains?

Hierarchical regression analysis was conducted to answer the research question, and visuospatial memory (Corsi_S) was included as the control variable. The ANOVA results of the models were presented in Table 12.

Table 12. ANOVA Results of the Ten Number Line Learning Gains

Model		Sum of Squares	df	Mean Square	*F*	*P*
1	Regression	56.00	1	56.00	1.72	.205[b]
	Residual	618.67	19	32.56		
	Total	674.67	2			
2	Regression	253.56	2	126.78	5.42	.014[c]
	Residual	421.10	18	23.39		
	Total	674.67	20			
3	Regression	253.57	3	84.52	3.41	.041[d]
	Residual	421.10	17	24.77		
	Total	674.67	20			

a. Dependent Variable: the ten number line learning gains

b. Predictors: (Constant), visuospatial working memory (Corsi_S)

c. Predictors: (Constant), visuospatial working memory (Corsi_S), mathematics achievement (MEA)

d. Predictors: (Constant), visuospatial working memory (Corsi_S), mathematics achievement (MEA), problem-solving scores (PSTS)

The results of the first block analysis revealed that the regression model was not significant ($p > .05$) (see Table 12), and visuospatial working memory performances were not sufficient to explain variances in ten number line gains. Thus, it was found that ten number line gains were not explained by individual differences in visuospatial memory (see Table 14).

Table 13. Results of Multiple Regression Model Fit Predicting the Ten Number Line Gains

Predictor	Model 1	Model 2	Model 3
Constant	.29	.61*	.61
	(11.92)	(42.19)	(42.20)
Visuospatial memory	.29	-.16	-.16
	(1.33)	(1.16)	(1.22)
Mathematics achievement		-.56	-.56
		(.14)	(.16)
Problem solving ability			-.00
			(.02)
R^2	8.3	37.6	37.6

Cell entries are estimated regression coefficients and standard errors *$p < .05$.

Note.Dependent Variable: the ten number line gains

The second block analysis was conducted, and the regression model was significant (p = .014) (see Table 12). As shown in Table 13, the problem-solving scores were included in the third block analysis; however, the model was not significant (p > .05). Therefore, the second model was chosen to approach research question 3a.

The mathematics exam averages (MEA) explained .29 % variances in the ten number line gains (F (2, 18) = 5.42, p = .009). Therefore, one standard deviation increase in ten number line learning gains would decrease .16 standard deviation visuospatial memory span, which implied that students with shorter memory span benefited more from the ten-number-line video game tasks. Additionally, one standard deviation increase in ten number line learning gains would decrease .56 standard deviation mathematics exam scores, which implied that low attainers in mathematics benefited more from the ten-number-line video game tasks.

4.3.5 Research question 3b

To what extent do working memory capacity, school mathematics exam grades, and mathematical problem-solving abilities of fourth-grade students explain variance in hundred number line gains?

Controlling visuospatial working memory performances (Corsi_S) hierarchical regression analysis was conducted to explain variances in hundred number line gains. ANOVA results and Coefficient results of the regression analysis were presented in Table 14.

Table 14. ANOVA Results of the hundred number line learning gains

Model		Sum of Squares	df	*MS*	*F*	*P*
1	Regression	81.97	1	81.97	3.37	.082[b]
	Residual	462.32	19	24.33		
	Total	544.29	20			
2	Regression	110.38	2	55.19	2.29	.130[c]
	Residual	433.91	18	24.11		
	Total	544.29	20			
3	Regression	110.43	3	36.81	1.44	.265[d]
	Residual	433.86	17	25.52		
	Total	544.29	20			
4	Regression	52.11	1	175.34	5.71	.172 [e]
	Residual	492.18	19	30.72		
	Total	544.29	20			

a. Dependent Variable: the hundred number line learning gains

b. Predictors: (Constant), visuospatial working memory (Corsi_S)

c. Predictors: (Constant), visuospatial working memory (Corsi_S), mathematics achievement (MEA)

d. Predictors: (Constant), visuospatial working memory (Corsi_S), mathematics achievement (MEA), problem solving scores (PSTS)

e. Predictors: (Constant), mathematics achievement (MEA)

The control variable was analyzed in the first block, and it was found that the model was not statistically significant $p > .05$. The visuospatial memory span did not predict hundred number line gains achievement (F (1, 19) = 3.37, $p > 0.5$) (see Table 15). The second and the third block analysis was conducted, the none of the models were found to be statistically significant in explaining variances in hundred number line gains ($p > .05$) (see Table 14). Therefore, the visuospatial memory and problem-solving ability variables were excluded in Model 4. However, Model 4 was not significant, and hundred number line gains could not be predicted by working memory performances, mathematics achievement, and problem-solving ability.

Table 15. Results of Multiple Regression Model Fit Predicting the Hundred Number Line Gains

Predictor	Model 1	Model 2	Model 3	Model 4
Constant	.39	.45	.45	.31
	(13.48)	(24.96)	(25.05)	
Visuospatial memory	-.39	-.34	-.34	
	(1.15)	(1.18)	(1.24)	
Mathematics achievement		-.23	-.24	-.31
		(.14)	(.16)	(.14)
Problem-solving ability			.01	
			(.02)	
R^2	15.1	20.3	20.3	30.9
Cell entries are estimated regression coefficients and standard errors *p < .05.				

Note. Dependent Variable: the hundred number line gains

4.3.6 Research question 3c

To what extent do working memory capacity, school mathematics exam grades, and mathematical problem-solving abilities of fourth-grade students explain variance in thousand number line scores?

The first block analysis was conducted, and the control variable was visuospatial working memory performances. The model was found to be not statistically significant (see Table 16).

Table 16. ANOVA Results of the Thousand Number Line Learning Gains

Model		Sum of Squares	df	Mean Square	*F*	*P*
1	Regression	16.34	1	16.34	0.42	.526[b]
	Residual	742.61	19	39.08		
	Total	758.95	20			
2	Regression	176.57	2	88.29	2.73	.092[c]
	Residual	582.38	18	32.35		
	Total	758.95	20			
3	Regression	201.00	3	67.00	2.04	.146[d]
	Residual	557.95	17	32.82		
	Total	758.95	20			
4	Regression	175.34	1	175.34	5.71	.027[e]
	Residual	583.62	19	30.72		
	Total	758.95	20			

Note Dependent Variable: the thousand number line learning gains

Predictors: (Constant), mathematics achievement (MEA)

The results of the first block analysis revealed that visuospatial memory performances did not explain thousand number line gains, and *R*-value was .15 ($p >$ .05) (see Table 17).

Table 17. Results of Multiple Regression Model Fit Predicting the Thousand Number Line Gains

Predictor	Model 1	Model 2	Model 3	Model 4
Constant	.15 (8.38)	.48* (35.64)	.52 (37.70)	.48* (34.84)
Visuospatial memory	-.15 (1.46)	-.04 (1.37)	-.00 (1.40)	
Mathematics achievement		-.47 (.16)	-.57 (.18)	-.48 (.15)
Problem solving ability			.20 (.03)	
R^2	2.2	23.3	26.5	23.1
Cell entries are estimated regression coefficients and standard errors *p < .05.				

Note. Dependent Variable: the thousand number line gains

The second block analysis included the mathematics achievement variable, and the model was not statistically significant (p > .05) (see Table 16). Therefore, visuospatial working memory performances were excluded from the analysis, and regression analysis was conducted with the mathematics achievement variable in Model 4.

To conclude, the fourth model was chosen to answer research question 3c, and results showed that mathematics exam averages predicted 23.1 % variances in thousand number line gains (F (1, 19) = 5.71, p = .039). Thus, one standard increase in thousand number line gains would decrease .48 standard deviation mathematics exam averages. This result implied that low achieving students in mathematics benefited more from thousand number line video game instruction.

4.3.7 Research question 4

How do students with different number sense gains use number sense strategies?

In this part of the study, interview results were presented as multiple cases. Students' scores regarding pretest and posttest were presented separately in the score tables, including six sections of the Basic Number Processing Test (BNPT). As number sense components depended on response time, the completion time of the random dot counting, canonical dot counting, and symbolic number comparison tasks was presented as RDC time, CDC time, and SNC time in the scores table. Along with each component of the BNPT, Table 18 summarizes the pretest and posttest means of 21 participants.

Table 18. Means of Basic Number Processing Pre-test and Post-test Results

	RDC score	RDC time	CDC score	CDC time	SNC score	SNC time	MNL10	MNL100	MNL1000	MNL total
Pre-test	19.90	79 sec	20.05	64 sec	20.19	37 sec	89.33	90.14	87.19	266.67
Post-test	20.04	77 sec	20.67	61 sec	20.09	35 sec	92	92.43	90.57	275
Maxscore	21	-	21	-	21	-	100	100	100	300

Note. RDC score: Random dot counting score, RDC time: Completion time of random RDC part, CDC score: Canonical dot counting score, CDC time: Completion time of CNC part, SNC score: Symbolic number comparison score, SNC time: Completion time of SNC part, MNL10: Estimation task of the number line from 0 to 10, MNL100: Estimation task of the number line from 0 to 100, MNL1000: Estimation task of the number line from 0 to 1000.

4.4 Qualitative Findings

4.4.1 First case

Rachel was a high attainer in fourth-grade mathematics, and she was among the students who obtain low number sense gain. Rachel obtained 344 in the pretest and 347 in the posttest, or more precisely, Rachel increased her overall score from 94.7 percent to 95.5 percent. There is no room to improve because of the ceiling effect.

Table 19. Rachel's Basic Number Processing Test Results

	RDC score	RDC time	CDC score	CDC time	SNC score	SNC time	MNL 10	MNL 100	MNL 1000	MNL total
Pre-test	21	95 s	20	63 s	21	37 s	95	94	93	282
Post-test	21	67 s	21	58 s	21	33 s	94	95	95	284
Mean-pre	19.90	79 s	20.05	64 s	20.19	37 s	89.33	90.14	87.19	266.67
Mean-post	20.04	77 s	20.67	61 s	20.09	35 s	92	92.43	90.57	275
Max score	21	-	21	-	21	-	100	100	100	300

In the RDC part, Rachel's pre-test score was 21 (M = 19.90, SD = 1.76) and her post-test score was 21 (M = 20.05, SD = 0.92). As can be seen in Table 19, Rachel answered all questions correctly, and her scores were above the mean of pretest and posttest. Rachel's interview data showed that she determined the exact number of dots by creating larger groups than other cases in this study. Rachel often mentioned that she decided the number of dots immediately, even for the larger sets out of the subitizing range. Rachel grouped the sets shown in Figure 7 as the following: five dots and two dots made seven, five dots, and three dots made eight, two, three, and four dots made nine.

Even though there was no room to improve her RDC score because of the ceiling effect, her response time decreased from 95 s (M = 79, SD = 16.37) to 67 s (M = 77, SD = 17.02). During the interview, she was asked how she quickly decided the number of random dot arrays in Figure 14. Rachel said she saw randomly placed dots as common patterns such as five on the dice "a random eight was composed of five and three, and five was like on the dice pattern… I symmetrical the shapes, and this method makes me fast". Rachel likened the random dot pattern to the five patterns on the dice and added the remaining three. Thus, creating larger and similar patterns during the gameplay complies with the decrease in her posttest reaction time.

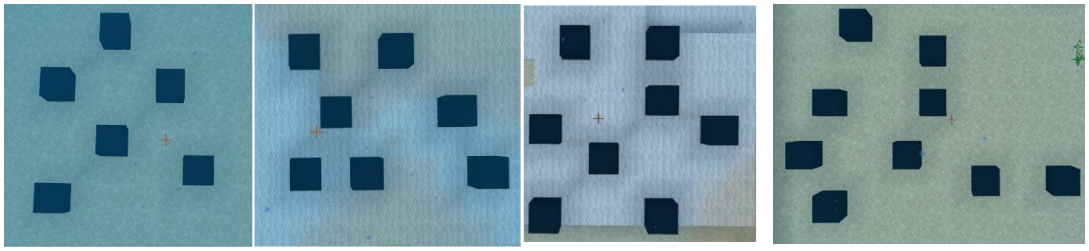


Figure 14. Dot arrays of random six, seven, eight, and nine

In CDC part, Rachel's score was 20 in pre-test (M = 20.05, SD = 0.92) and 21 in the post-test (M = 20.67, SD = 0.48). Rachel's response time decreased from 63 s (M = 64, SD = 13.54) to 58 s (M = 61, SD = 15.34). Rachel grouped the canonical objects as the following: five was the dice pattern, six was six, seven were four and three, eight was a unified eight, nine was five and four, ten was four and six (see Figure 15).

Rachel's grouping strategy was different from other participants, and she preferred to group the six and eight as single sets rather than partitioning them into smaller groups. Instead, Rachel created larger sets in random and canonical arrays. Rachel said that "for shapes like this (six), there is no need to split into small pieces as it appears as a unified shape."

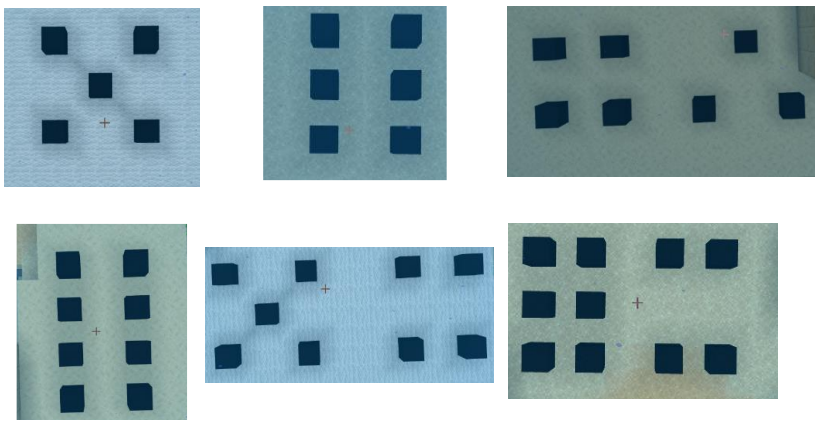


Figure 15. Dot arrays of canonical five, six, seven, eight, and nine

Rachel stated that she completed the dot enumeration tasks in about 9 minutes, less than half of the activity time. Before the interview, Rachel's screen recordings were reviewed to compare her actions during the gameplay and her responses during the interview. Rachel's answers were consistent, and she spent a very short amount of time compared to other cases in deciding the number of dots. She dived in, quickly determined the number of the objects, and selected the correct option.

As can be seen in Table 20, Rachel's working memory span was 6 items, larger than the group (M = 5.29, SD = .96). Thus, Rachel created larger groups and spent less time when counting objects as she had a larger visuospatial memory span. Rachel's inhibitory control performance reduction was -35 % and below the mean, and her mean response time in the attention task (GNG-MRT) was above the group. Rachel's inhibition and attention performances were similar to her performances in the random dot counting task. That is, Rachel spent more time than the group completing pretest random-dot counting (see Table 20).

Table 20. Rachel's Working Memory Results

	SE	SB	SI	SR	Corsi span	Go/no-Go MRT
WMB	318	906 ms	1224	-35 %	6 items	590 ms
Mean	208.29	1080 ms	1289 ms	-20 %	5.29 items	441 ms

a. SE indicates the Stroop effect calculated by subtracting SB from SI.
b. SI indicates response times in ms when incongruent stimuli appear on the screen
c. SB indicates response times in ms when congruent stimuli appear on the screen.
d. SR indicates Stroop reduction calculated by SB-SI/ SB.
e. Corsi span is a visuospatial memory span.
f. Go-no-Go represents the measure of attention calculated by mean response times of correct responses

Prior to the intervention Rachel was very accurate in the number line estimation tasks and her MNL pre-test results were 95 (M = 89.33, SD = 6.07), 94 (M = 90.14, SD = 5.65), and 93 (M = 87.19, SD = 7.37), respectively. After the

intervention, Rachel's MNL post-test results were 94 (M = 92, SD = 2.05), 95 (M = 92.43, SD = 2.99), and 95 (M = 90.57, SD = 4.61). Thus, video game intervention had no effect on her number line estimation gains because of ceiling effect.

During the interviews, Rachel was asked about her mental number line strategies to understand the quantitative results of the research. When playing 10, 100, and 1000 number line tasks, Rachel said that she used the middle point strategy for 3, 4, 5, 6, 42, 52, 352, 504, 612, and 724 numbers. Rachel explained the location of 52 on the 0 to 100 number line, "I decide 52 according to the location of 50. I find the middle point, which is 50, then I move just a little forward. I find 504 just in the middle and move right slightly." Moreover, Rachel used the beginning point strategy for 2, 29, 33, and 240 numbers and used the end-point strategy for 7, 8, 9, and 90.

Additionally, she used many positive statements when she answered game flow questions. Rachel said that the thousand number line task was her favorite task as this task was challenging. She answered that if there were other tasks, she would prefer the thousand number line to others. She said that stories were realistic, the game environments were intriguing, the tasks were amusing, and she would have played if there were other tasks.

4.4.2 Second case

Luna was one of the students who got low number sense gain. Increasing her score from 91% to 92%, Luna had 331 in the pretest and 334 in the posttest. As shown in Table 21, intervention did not improve Luna's score for the RDC, but her response time decreased from 99 s (M = 79, SD = 16.37) to 79 s (M = 77, SD = 17.02). It is clear that Luna's response time for the RDC remarkably decreased and approximated the mean response time of the posttest. Additionally, Luna's score did not improve

for the CDC and her response time was 65 s (*M* = 64, *SD* = 13.54) in the pre-test and 62 s (*M* = 61, *SD* = 15.34) in the post-test.

Table 21. Luna's Basic Number Processing Test Results

	RDC score	RDC time	CDC score	CDC time	SNC score	SNC time	MNL 10	MNL 100	MNL 1000	MNL total
Pre-test	21	99 s	20	65 s	21	46 s	93	90	86	269
Post-test	20	79 s	20	62 s	21	34 s	92	93	88	273
Mean-pre	19.90	79 s	20.05	64 s	20.19	37 s	89.33	90.14	87.19	266.67
Mean-post	20.04	77 s	20.67	61 s	20.09	35 s	92	92.43	90.57	275
Max score	21	-	21	-	21	-	100	100	100	300

In the interviews, Luna grouped canonical five patterns as "four on the corners and five in the middle." (see Figure 16). Luna also described how she grouped seven random objects as follows:

> "At first, I counted three and added three more which made six. I would have chosen the "six" option. However, I decided to count again, and I saw one object more, and I choose seven. "

When she was shown four random objects, she responded as follows:

> "I see this one was just four. I can easily memorize and enumerate smaller sets, but I cannot memorize bigger sets as I have difficulty remembering some objects. I need to dive again to count when I am working with bigger sets. "

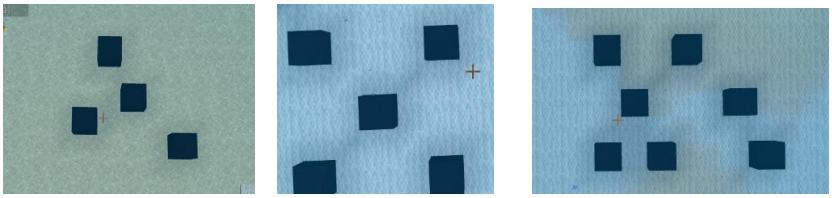


Figure 16. Dot arrays of random four, canonical five, and random seven

Luna's statements implied that she repeatedly counted the larger sets and had difficulty tracking the screen. Luna's visuospatial memory span was smaller than the group (*M* = 5.29, *SD* = .96), which was 5 items (see Table 23). Additionally, Luna's

Stroop reduction percentage was -47 % (*M* = -20, *SD* = 14.24) implied she had low inhibitory control, namely difficulty in inhibition of irrelevant information. Luna's mean response time (499 ms) in the attention task was also above the mean. Luna's Working Memory Battery results were congruent with her response time results in random dot counting and canonical dot counting tasks (see Table 22). That is, she spent more completion time than the group in the pretest (see Table 21).

Table 22. Luna's Working Memory Results

	SE	SB	SI	SR	Corsi span	Go/no-Go MRT
WMB	489 ms	1045 ms	1534	-47 %	5 items	499 ms
Mean	208.29	1080 ms	1289 ms	-20 %	5.29 items	441 ms

a. SE indicates the Stroop effect calculated by subtracting SB from SI.
b. SI indicates response times in ms when incongruent stimuli appear on the screen
c. SB indicates response times in ms when congruent stimuli appear on the screen.
d. SR indicates Stroop reduction calculated by SB-SI/ SB.
e. Corsi span is a visuospatial memory span.
f. Go-no-Go represents the measure of attention calculated by mean response times of correct responses

Luna's MNL pre-test and post-test results were shown in Table 22. Luna's pre-test MNL scores were 93 (*M* = 89.33, *SD* = 6.07), 90 (*M* = 90.14, *SD* = 5.65), and 86 (*M* = 87.19, *SD* = 7.37). Luna's post-test results were 92 (*M* = 92, *SD* = 2.05), 93 (*M* = 92.43, *SD* = 2.99), and 88 (*M* = 90.57, *SD* = 4.61). Luna increased her total mental number line score 4 points which was a slight improvement compared to the 8.33 points of difference between means of pre-test and post-test total mental number line scores.

When working on mental number line activities in the game, Luna used the middle point strategy for five on the ten-number line and 52 on the hundred number line. Second, she used the beginning point strategy for three on the ten-number line. Lastly, she used end-point strategy for nine on the ten-number line, for 90 on the hundred-number line, and 950 on the thousand-number line. It was apparent that

Luna's strategies were deficient in number compared to Rachel's strategies. Luna clearly stated she had no strategies to find 25, 29, and 42 on the hundred number line and responded, "I am not good at number line tasks at all. I do well only on the ten-number line task. I do not have any strategy when working on the hundred and on the thousand number lines. I mostly jump to find the number. I found the location of 50 correctly, but 20s and 40s were always incorrect".

Luna said that she had enjoyed playing Minecraft tasks very much. In particular, she said she favored the diving and counting missions. Luna also stated she felt that her estimations became better after playing the game.

4.4.3 Third case

Darcey's number sense gain was one of the moderately improved results. Darcey's number sense scores were improved from 90,3% to 96,1%, and her total scores were 328 in the pretest and 349 in the posttest.

Table 23. Darcey's Basic Number Processing Test Results

	RDC score	RDC time	CDC score	CDC time	SNC score	SNC time	MNL 10	MNL 100	MNL 1000	MNL total
Pre-test	21	62 s	21	53 s	14	30 s	92	92	88	272
Post-test	21	59 s	21	50 s	21	26 s	93	97	96	286
Mean-pre	19.90	79 s	20.05	64 s	20.19	37 s	89.33	90.14	87.19	266.67
Mean-post	20.04	77 s	20.67	61 s	20.09	35 s	92	92.43	90.57	275
Max score	21	-	21	-	21	-		100	100	300

Darcey's RDC pre-test score was 21 (M = 19.90, SD = 1.76) and her RDC post-test score was 21 (M = 20.05, SD = 0.92). Darcey's scores in CDC part were 21 in the pre-test (M = 20.05, SD = 0.92) and 21 in the post-test (M = 20.67, SD = 0.48). This showed that video game treatment did not affect her scores in the RDC and in the CDC parts. However, her response time decreased from 62 s (M = 79, SD

= 16.37) to 59 s (*M* = 77, *SD* = 17.02) in RDC part, and decreased from 53 s (*M* = 64, *SD* = 13.54) to 50 s (*M* = 61, *SD* = 15.34) in the CDC part.

Darcey's dot enumeration test results showed that her response time scores in all RDC and CDC tests were below the mean. Darcey created larger groups when counting the sets. During the interview, Darcey grouped canonical 10 set as 8 and 2 by responding," then I count one side of the group, I understand this is eight and two more in the middle add up to 10." She grouped canonical five as five "I see four on the corners and one in the middle." She grouped random 10 set as the following" I group this one as 5 and 5, and I said 10."(see Figure 17).

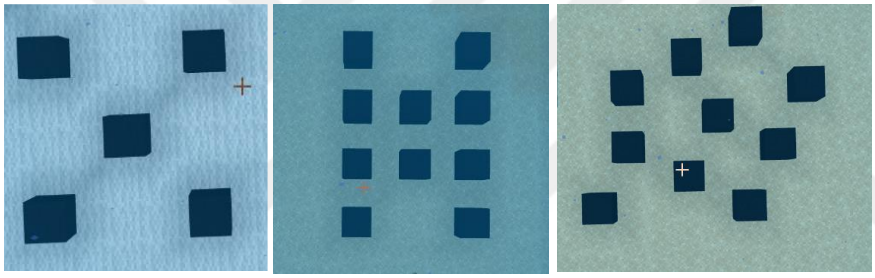


Figure 17. Dot arrays of canonical five, canonical ten, and random ten

As shown in Table 24, Darcey's inhibitory control reduction percentage was -.21 and nearly equaled the mean. This indicated Darcey's inhibition performance was close to the group; however, Darcey had a slightly smaller visuospatial memory span than the group (see Table 24). Darcey's mean response time in the attention task (GNG) was also smaller than the group. Darcey's inhibitory control performance and attention performance were high, and this result was parallel with her dot enumeration performance. Therefore, Darcey had shorter response times than the group in all dot enumeration tasks (see Table 23).

Table 24. Darcey's Working Memory Results

	SE	SB	SI	SR	Corsi span	Go/no-Go MRT
WMB	250 ms	1169 ms	1419 ms	-21%	5 items	363 ms
Mean	208.29	1080 ms	1289 ms	-20 %	5.29 items	441 ms

a. SE indicates the Stroop effect calculated by subtracting SB from SI.
b. SI indicates response times in ms when incongruent stimuli appear on the screen
c. SB indicates response times in ms when congruent stimuli appear on the screen.
d. SR indicates Stroop reduction calculated by SB-SI/ SB.
e. Corsi span is a visuospatial memory span.
f. Go-no-Go represents the measure of attention calculated by mean response times of correct responses

As shown in Table 23, Darcey increased her total MNL score 14 points and the difference was moderate compared to 8.33 difference of means. Darcey's pre-test MNL scores were 92 (M = 89.33, SD = 6.07), 92 (M = 90.14, SD = 5.65), and 88 (M = 87.19, SD = 7.37). Darcey's post-test MNL results were 93 (M = 92, SD = 2.05), 97 (M = 92.43, SD = 2.99), and 96 (M = 90.57, SD = 4.61).

Darcey's screen recordings for ten and thousand MNL tasks were not taken because she forgot to record her task activity. Therefore, she was interviewed only for 0 to 100 number lines. Darcey used the middle point strategy for 29 and 42 on the 0 to 100 number line. She used a mix of middle point and beginning point strategies to find 25. She described, "I found 25 as same as I found 29… At first, I located 50 and 20, respectively. I moved to the left to spot 29." Additionally, she used the beginning point strategy for 7 and 21. "I moved to the zero as seven was close to 0, not to 100…If the number was close to 0, I moved toward 0. If the number was close to 100, I moved toward 100." Darcey's statements demonstrated that the beginning and end-point strategy was used frequently.

Darcey said that the tasks were splendid as there were scenarios about keeping the environment clean. She also stated that Minecraft number sense tasks made mathematics lessons more exciting and entertaining. Darcey explained," It was funny to learn mathematics by playing a game…I would like to play more Minecraft

tasks like these." According to Darcey's statements, she experienced concentration, effortless involvement, and loss of sense of time when she played the game tasks. However, she stated she had some difficulty controlling her actions when playing initial tasks.

4.4.4 Fourth case

Adrian was a high attainer student in mathematics who got moderate number sense gain. Adrian obtained 332 points in the pretest, which was 91,4%. Adrian's posttest score was 344 points and 94,7%.

Table 25. Adrian's Basic Number Processing Test Results

	RDC score	RDC time	CDC score	CDC time	SNC score	SNC time	MNL 10	MNL 100	MNL 1000	MNL total
Pre-test	21	66 s	21	54 s	21	30 s	88	90	91	269
Post-test	20	64 s	21	45 s	21	31 s	94	94	94	282
Mean-pre	19.90	79 s	20.05	64 s	20.19	37 s	89.33	90.14	87.19	266.67
Mean-post	20.04	77 s	20.67	61 s	20.09	35 s	92	92.43	90.57	275
Max score	21	-	21	-	21	-	100	100	100	300

Adrian's RDC pre-test score was 21 (M = 19.90, SD = 1.76) and his RDC pre-test response time was 66 s (M = 79, SD = 16.37). Adrian's RDC post-test score was 20 (M = 20.05, SD = 0.92) and his RDC post-test response time was 64 s (M = 77, SD = 17.02). During the interview, Adrian created larger groups when random arrays in Figure 18 were shown to him. Adrian grouped random objects as following: two fours and a two add up to 10, three and one made 4, and three and two made 5. Adrian grouped ten random objects by fours instead of grouping by three or two. Adrian counted the objects with larger groups, and his completion time of the task was below average, both in pretest and posttest. This result implied that Adrian had a wide subitizing range; therefore, he spent less time counting the objects.

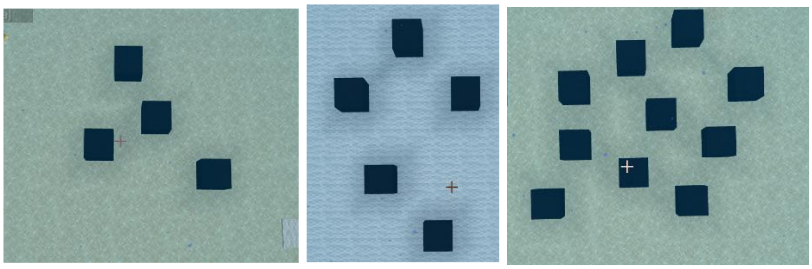


Figure 18. Dot arrays of random four, random five, and random ten

In CDC part, Adrian's pre-test score was 21 (M = 20.05, SD = 0.92) and his response time was 54 s (M = 64, SD = 13.54). Adrian's CDC post-test score was 21 (M = 20.67, SD = 0.48) and his response time was 45 s (M = 61, SD = 15.34). Even though Adrian's CDC score remained the same, response time in the CDC posttest decreased by 9 seconds. Adrian was one of the participants who made larger groups of canonical arrays. He grouped canonical nine as three by three and five plus four (see Figure 19).

Adrian's CDC post response time was 16 s below the mean. As stated in the previous cases, students performed the canonic tasks by visualizing familiar patterns. Since Adrian's subitizing range was large, he probably memorized canonical patterns which were not familiar before playing the game. On the other hand, he may have created his own patterns while playing the game. These arguments may explain the decrease in CDC post-test response time.

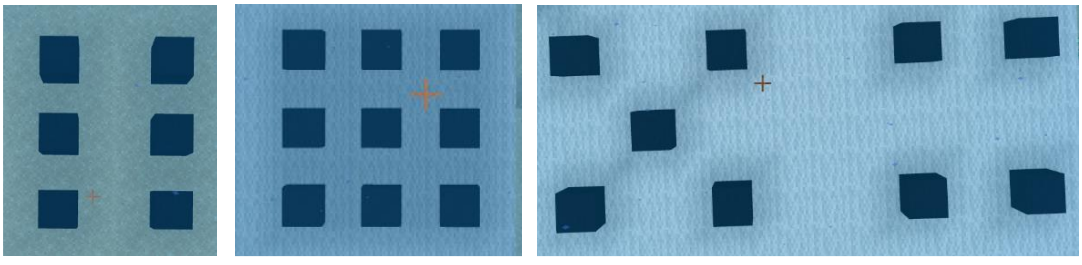


Figure 19. Dot arrays of canonical six, nine, and grouped nine.

Moreover, he grouped six as a whole and explained, “I do not need to count this one. I have always seen the same sequences in real life; it is obviously six”. Thus, there is a substantial similarity between the explanations of Adrian and Rachel about grouping canonical 6. They grouped six arrays as a whole set instead of partitioning.

Adrian’s inhibitory control reduction performance and attention performances were -23% (*M* = -20, *SD* = 14.24) and 375 ms (*M* = 452.89, *SD* = 108.94), respectively (see Table 26). This indicated Adrian had high inhibitory control and attention performances. Therefore, Adrian’s response times in dot enumeration tasks were below the mean (see Table 25).

Table 26. Adrian’s Working Memory Results

	SE	SB	SI	SR	Corsi span	Go/no-Go MRT
WMB	242 ms	1028 ms	1270 ms	-23%	6 items	375 ms
Mean	208.29	1080 ms	1289 ms	-20%	5.29 items	441 ms

a. SE indicates the Stroop effect calculated by subtracting SB from SI.
b. SI indicates response times in ms when incongruent stimuli appear on the screen
c. SB indicates response times in ms when congruent stimuli appear on the screen.
d. SR indicates Stroop reduction calculated by SB-SI/ SB.
e. Corsi span is a visuospatial memory span.
f. Go-no-Go represents the measure of attention calculated by mean response times of correct responses

As shown in Table 25, Adrian’s mental number line scores were improved in three types of number line tests. Adrian’s pre-test MNL scores were 88 (*M* = 89.33, *SD* = 6.07), 90 (*M* = 90.14, *SD* = 5.65), and 91 (*M* = 87.19, *SD* = 7.37). After the intervention, Adrian had 94 (*M* = 92, *SD* = 2.05), 94 (*M* = 92.43, *SD* = 2.99), and 94 (*M* = 90.57, *SD* = 4.61) in the MNL post-test. Thus, Adrian improved his total MNL score 13 points after completing number sense tasks.

Adrian used the following strategies in MNL 1000 number line: middle point strategy for 564, beginning strategy for 32, 124, and 158, end-point strategy for 768, 820, and 880. Adrian explained how he found 768:

> "I located 768 somewhere between 700 and 800. I do this by drawing an imaginary line to 800. I do not know how this happens. However, I think I have an innate ability to locate the numbers on 0 to 10 number line."

Adrian mentioned that he had an innate ability for the 0-10 range of number line but not for the 0-100 and 0-1000 ranges. Completing consecutive and complementary tasks with Minecraft game activity provided him to use his ability on the other number line tasks.

Thus, Adrian's statements indicate two critical results. First, Adrian transferred his knowledge of 0 to 10 number line on 0 to 1000 number line. In addition, he was aware of an imaginary map, i.e., mental number line, when using strategies.

4.4.5 Fifth Case

Zoey was a low-achieving student in mathematics, and her number sense scores have greatly improved. Zoey's total score increased from 276 (76%) to 317 (87,3%) out of 363. Zoey's RDC score have not improved however her response time in RDC decreased from 98 s (M = 79, SD = 16.37) to 79 s (M = 77, SD = 17.02).

Table 27. Zoey's Basic Number Processing Test Results

	RDC score	RDC time	CDC score	CDC time	SNC score	SNC time	MNL 10	MNL 100	MNL 1000	MNL total
Pre-test	20	98 s	21	81 s	20	35 s	73	72	70	215
Post-test	20	79 s	20	78 s	21	28 s	90	86	80	256
Mean-pre	19.90	79 s	20.05	64 s	20.19	37 s	89.33	90.14	87.19	266.67
Mean-post	20.04	77 s	20.67	61 s	20.09	35 s	92	92.43	90.57	275
Max score	21	-	21	-	21	-	100	100	100	300

Examination of Zoey's video recordings revealed that she spent plenty of time counting the random 10. During the interview, she was shown the sequence random 10, and she said, "there are nine objects. I counted by dividing into groups of two." (see Figure 20). After giving Zoey some time to think again, she was told the correct answer. Zoey also incorrectly answered the canonical 9 "I see ten here. The objects are arranged in groups of three." Zoey's counting mistakes indicated that she had difficulty keeping track of previously counted objects. This type of mistake was also observed during Luna's interviews.

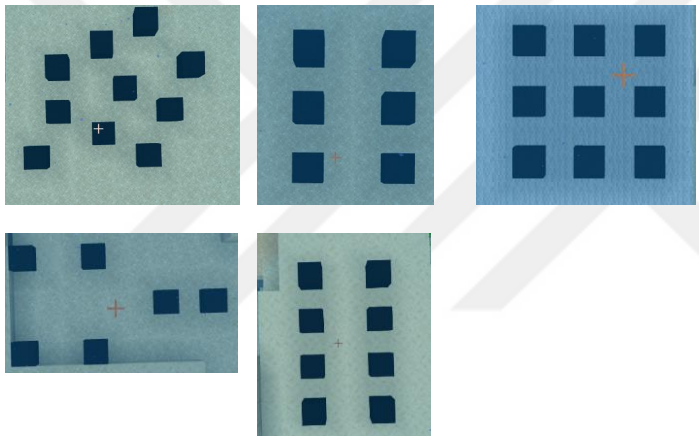


Figure 20. Dot arrays of random ten, canonical six, seven, eight, and nine

Moreover, there was a similarity between the RDC and CDC results of Zoey and Luna. None of the other cases but Luna and Zoey had incorrect answers in the enumeration parts of pretest and posttest. Luna's and Zoey's RDC response time scores were also close to each other (see Table 27 and Table 21). Zoey preferred to count random 10 by partitioning into smaller sets and creating smaller sets when counting, which probably extended the response time.

Zoey's inhibitory control reduction was -2% (*M* = -20, *SD* = 14.24), attention performance was 645 ms (*M* = 452.89, *SD* = 108.94), and visuospatial memory span was 3 (*M* = 5.29, *SD* = .96)(see Table 28). Surprisingly, Zoey had a remarkably small inhibitory reduction, which indicated she had no difficulty inhibiting inconsistent stimuli. However, Zoey's response times in the attention task were above the mean; namely, she had difficulty keeping up with the task. Last, her memory span was considerably smaller than the group. These results indicated that Zoey had a longer completion time than means of all dot enumeration tasks (see Table 27).

Table 28. Zoey's Working Memory Result

	SE	SB	SI	SR	Corsi span	Go/no-Go MRT
WMB	26 ms	1131 ms	1157 ms	-2%	3 items	645 ms
Mean	208.29	1080 ms	1289 ms	-20%	5.29 items	441 ms

a. SE indicates the Stroop effect calculated by subtracting SB from SI.
b. SI indicates response times in ms when incongruent stimuli appear on the screen
c. SB indicates response times in ms when congruent stimuli appear on the screen.
d. SR indicates Stroop reduction calculated by SB-SI/ SB.
e. Corsi span is a visuospatial memory span.
f. Go-no-Go represents the measure of attention calculated by mean response times of correct responses.

Even though Zoey's inhibitory control performance was high, she created small groups when counting random and canonical objects in the video game. This result may be explained by Zoey's small memory span and low attention performance. Either she created smaller groups because she had a small memory span or having attention difficulty made it harder for Zoey to track the objects on the screen.

Zoey's MNL pre-test scores were 73 (*M* = 89.33, *SD* = 6.07), 72 (*M* = 90.14, *SD* = 5.65), and 70 (*M* = 87.19, *SD* = 7.37), respectively. After the intervention, Zoey's total MNL scores increased 47 points, notably above the mean increase of MNL scores of 8.33. Zoey's MNL post-test scores were 90 (*M* = 92, *SD*

= 2.05), 86 (*M* = 92.43, *SD* = 2.99), and 80 (*M* = 90.57, *SD* = 4.61). Zoey used the mid-point strategy to locate 5, 2, 3, 4, and 8 on the ten-number line. Zoey explained," Five is in the middle. I locate two, three, and four by subtracting from five. To find the eight, I added three to five". To evaluate Zoey's proportional ability, she was asked how many blocks had to be taken in order to advance a number. She answered as two blocks, a reasonable answer because the actual value was two and a half Minecraft blocks.

Even though eight was closer to ten than five, Zoey located the 8 using a mid-point strategy instead of an end-point strategy. Additionally, Zoey found the location of 2 using mid-point strategy instead of beginning-point strategy. However, she used the end-point strategy to find 9 on ten number lines. These three situations indicated that Zoey has failed to evaluate the proximity among some numbers.

Zoey could not record the hundred-number line task because of technical problems with her computer. That is why the hundred number line was not included in her interview. Zoey's posttest MNL score for the thousand number line increased 10 points; however, her score was still under the mean point of 90.57.

Zoey described how she found 158 and 240 on the thousand-number line" I find the 100, then I add up 58 blocks… I found 240 by locating 100 and 200 respectively". At first, Zoey tried to find 158 and 240 by beginning point strategy. When Zoey was not able to locate the 158, she used the middle-point strategy. Evaluating proximity of numbers, she performed better on the thousand number line than on the ten-number line as 158 and 240 were closer to 0 than 500.

However, Zoey's recordings were not consistent with her description of the location of 158, and she was encouraged to explain in detail. Thus, she provided a different explanation" I find the middle of the hundred number line, then I move

back from 500 to 100. I move forward a short distance to find 158." Zoey also used the middle point strategy for 612 and 724 and explained, "I find the middle which is 500 and move right 100 and 12 right. I find 724 by adding 200 and 24 to 500."

Zoey's explanations pointed out that Zoey made progress in proximity evaluation at the end of the number line tasks. As the 2 was close to the beginning point, she has found the 2 by using the mid-point strategy on the ten-number line task. However, she switched from the beginning point strategy to the mid-point strategy for 158, which she got used to doing. Zoey probably needed more practice to apply her knowledge on the thousand number line.

Zoey stated that the games were exciting and funny. She said that diving tasks were her favorite, as she continuously increased her score and had fewer errors when counting. Interestingly, Zoey said she learned how to find mid-point on number line tasks. This showed that number line tasks helped Zoey to locate the middle point of a number line accurately.

4.4.6 Sixth case

Emily was a low achieving student in mathematics and obtained high number sense gain after the intervention. Emily's total scores were 282 in the pretest and 342 in the posttest. Increasing her total score from 77,6% to 94,2%, Emily benefited most from the intervention.

Table 29. Emily's Basic Number Processing Test Results

	RDC score	RDC time	CDC score	CDC time	SNC score	SNC time	MNL 10	MNL 100	MNL 1000	MNL total
Pre-test	21	95 s	19	94 s	20	35 s	74	76	72	222
Post-test	21	78 s	21	66 s	21	33 s	92	95	92	279
Mean-pre	19.90	79 s	20.05	64 s	20.19	37 s	89.33	90.14	87.19	266.67
Mean-post	20.04	77 s	20.67	61 s	20.09	35 s	92	92.43	90.57	275
Max score	21	-	21	-	21	-	100	100	100	300

In the RDC part, Emily's scores have not improved, nonetheless, response time decreased from 95 s (M = 79, SD = 16.37) to 78 s (M = 77, SD = 17.02) (see Table 29). When Emily's enumeration methods were asked, she generally created groups including a maximum of three objects. For instance, Emily said, "Random 4 is two plus two…random 9 is three times three."

Emily explained, "I saw some patterns when counting random 10. There are three and two which made five (3 + 2) and three more which look like a cat face and there is one more all add up to six (3 + 2 + 3 + 1 = 6). Lastly, there is another cat face and one which adds up to ten". Even though she ended up with the correct answer, Emily counted the same objects repeatedly. Emily was shown a random 10 sequence after a while. Thereafter, she counted random 10 as 3 + 3 = 6, 6 +1 = 7, 7 + 2 = 9, and 9 + 2 = 11. When Emily was told the correct answer, she said she counted one object twice. What Emily said for the random 10 groups during the interview revealed something quite important. Emily used to group random objects by two or three, and she has failed to track previously counted objects.

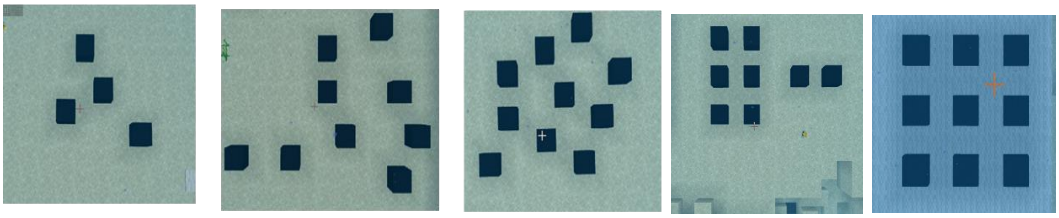


Figure 21. Dot arrays of random four, nine, ten and canonical eight and nine

In the CDC post-test, Emily answered all the questions correctly, and her response time decreased from 94 s (*M* = 64, *SD* = 13.54) to 66 s (*M* = 61, *SD* = 15.34). Even as Emily's response time improved considerably, her reaction time of the CDC posttest fell behind the mean. Emily mistakenly grouped canonical nine in

Figure 21 as twelve “There is three times three, which makes nine. I see three more, and the total is 12.” Additionally, Emily counted canonical eight (see Figure 21) as the following: six objects arranged in pairs from top to bottom and two adjacent objects totaling eight. Emilie, too, formed small groups while counting the objects, as Luna and Zoey did. Indeed, three of the cases made mistakes when they counted random 10.

Emily’s inhibition performance reduction was -27% (*M* = -20, *SD* = 14.24), attention performance was 406 ms (*M* = 452.89, *SD* = 108.94), and visuospatial memory performance was 5 items. Emily’s inhibitory control performance was below the mean, and her pretest random dot counting and canonic dot counting response times were considerably longer than the mean response times of the pretest (see Table 30). Therefore, Emily considerably improved her dot enumeration scores and response times after intervention.

Table 30. Emily’s Working Memory Results

	SE	SB	SI	SR	Corsi span	Go/no-Go MRT
WMB	318 ms	1173 ms	1491 ms	-27%	5 items	406 ms
Mean	208.29	1080 ms	1289 ms	-20%	5.29 items	441 ms

a. SE indicates the Stroop effect calculated by subtracting SB from SI.
b. SI indicates response times in ms when incongruent stimuli appear on the screen
c. SB indicates response times in ms when congruent stimuli appear on the screen.
d. SR indicates Stroop reduction calculated by SB-SI/ SB.
e. Corsi span is a visuospatial memory span.
f. Go-no-Go represents the measure of attention calculated by mean response times of correct responses

Emily’s total MNL results were improved significantly after the intervention. Emily made a significant advance on MNL-10 scores, which raised from 74 (*M* = 89.33, *SD* = 6.07) to 92 (*M* = 92, *SD* = 2.05). Emily used the middle-point strategy to locate 2, 3, 5, and 7, but she used the end-point strategy to find 9. Emily said that:

> "I find 5, 50, and 500 in the middle. Furthermore, I use the middle when locating numbers. I discovered this strategy during the second number line map, then I tried, and I saw it worked out."

Emily's explanation demonstrates that number line tasks supported her in adopting a strategy. Emily's MNL-100 scores also increased critically (see Table 29). Emily said she had difficulty locating the numbers on the hundred and thousand number lines. Therefore, she drew a hundred-number line prototype on paper and divided the number line into ten equal pieces. Afterward, Emily utilized her new strategy to locate the numbers by dividing with imaginative lines digital number lines into ten equal pieces. To locate numbers on the hundred-number line, Emily used the middle point strategy for 33, 42, 52 as well as 81, and the beginning-point strategy for 25. When locating these numbers, she also used the end-point strategy to find 96.

Emily's MNL-1000 scores were 72 (M = 87.19, SD = 7.37) in the pretest and 92 (M = 90.57, SD = 4.61) in the posttest. The middle point strategy was used to pinpoint 158, 612, 468, and 724. Emily found the thousand-number line task challenging and gave some inconsistent descriptions of her way of thinking. Nevertheless, the MNL posttest results of Emily were quite promising. To perform the hundred number line task, Emily created her concrete hundred number line and divided the intervals into ten equal pieces. She made more accurate estimations on the thousand number line task and increased her scores on the MNL1000 posttest. Along with the quantitative results, the interview of Emily shows that she transferred her new skills, which she learned in the hundred tasks, to the thousand number line task. Emily's opinions about the game were positive, and she described the tasks as appealing and engaging. Emily said that doing Minecraft tasks made her like mathematics more. At the end of the interview, she requested more tasks to learn new mathematics concepts.

CHAPTER 5

DISCUSSION AND CONCLUSION

The present study was conducted to explore the effect of using Minecraft video games on number sense ability improvement. The Minecraft activities, including specifically designed activities to improve enumeration and mental number line skills, were applied to fourth-grade students for four weeks (310 min). The first research question concerned whether video game activities were effective in improving the number sense abilities of fourth-grade students. The quantitative results revealed that students' number sense abilities were significantly improved after the videogame intervention.

The qualitative findings confirmed that videogame intervention was an effective method to improve enumeration and number line estimations of fourth-graders. Interview results showed that analyzing students' video game movements was an effective way to understand students' enumeration and number line strategies. That is, students who had low number sense scores counted objects in the video game by creating small groups. In addition, students with small subitizing range had difficulties in memorizing the number of objects they already counted. The results of each research question, limitations of the study, and further research questions were discussed in detail.

5.1 The potential benefits of video game activities on number sense development

The first question sought to answer the effects of video game activities on fourth-grade students' number sense development. The number sense development was measured by pre and post-test differences in dot enumeration, symbolic number

comparison, and mental number line scores. In the following section, the major findings of the first question were explained in detail.

5.1.1 The number sense abilities of the students

The results have shown that students' overall number sense scores were improved significantly after playing video game activities and the effect size of this difference was moderate (z = -2.58, p = .010, r^2 = .56). These results were consistent with the previous literature that adaptive and constructivist digital games supported number sense development (Kermani, 2017; Kiili, Devlin, Perttula, Tuomi, & Lindstedt, 2015; Pope & Mangram, 2015), especially for low attainer students who need more time and active learning (Laurillard, 2016).

Moreover, low achieving students have longer response times and smaller subitizing ranges than typical achieving students when performing dot enumeration tasks (Gray & Reeve, 2014). Similarly, an eye-tracking study revealed that typically achieving students used adaptive grouping strategies to enumerate and had shorter response times than students with mathematical difficulties (Schindler, Schovenberg, & Schabmann, 2020). Qualitative findings of this study indicated that low achieving students divided random dot arrays into smaller groups, and they had longer response times than typical and high achieving students. In this study, low achieving students' posttest response times were considerably lower than the pretest response times after playing dot enumeration tasks in Minecraft. Therefore, Minecraft dot enumeration games were likely to improve the response time performances of low attainers.

Even though students' posttest scores were statistically improved, there were no differences between pretest and posttest response times in random-dot counting, canonical dot counting, and symbolical number comparison tasks. However, small

effect size values were found after analyzing differences between response times. Since the sample size was limited in this study, a larger sample may show a difference between pre and post-response times.

The hundred and the thousand posttest number line scores were improved significantly except ten number line posttest scores, and the effect size of differences was the highest in thousand number line. This pattern of results was consistent with the previous literature that fourth graders displayed logarithmic representations for 0-1000 and 0-100 number line estimation, while they displayed linear representations for 0-10 number line estimation (Booth & Siegler, 2006; Siegler & Opfer, 2003). Similarly, students' pretest and posttest performances in thousand number line tasks were the lowest among other number line performances.

There were two possible explanations for these results. First, 0-10 and 0-100 number line activities improved students' thousand number line estimations, as students transferred their abilities to thousand number line tasks. Second, students benefited from the thousand number line game the most because it was more challenging for their age group.

Qualitative findings showed that fourth-grade students benefited in different levels from number line video game activities. Students with the lowest pretest estimation scores learned benchmark strategies necessary for number line estimation skills. Students with typical estimation pretest scores had opportunities to practice their mental calculation skills when playing number line video game tasks. It was, however, undeniable that videogame number line activities improved students' number line estimation skills.

5.1.2 The role of executive functions, mathematics achievement, and problem-solving skills in explaining individual differences in dot enumeration performances

In this study, bivariate correlation analysis and hierarchical regression analysis were conducted to explore correlations and relations between predictor variables (i.e., mathematics achievement, executive functions, problem-solving) and outcome variables (i.e., random dot enumeration and canonic dot enumeration performances). In addition, inverse efficiency scores of dot enumeration performances were calculated to integrate speed and accuracy (Gray & Reeve, 2014).

Findings revealed that random enumeration inverse efficiency scores moderately correlated with mathematics achievement scores (r = -.44). On the contrary, canonical dot enumeration inverse efficiency scores were not correlated with mathematics achievement scores. It is found that the random dot enumeration process requires more attentional resources (Schindler et al., 2020), and those cognitive abilities were probably needed when performing calculations in mathematics tests.

Hierarchical analysis was conducted to explore the effect of mathematics achievement, mathematical problem solving, executive functions, and working memory on dot enumeration performances. The mathematics achievement predicted the dot enumeration performances over and above cognitive abilities (F (4, 16) = 4.81, p = .016, r = -.49). Findings revealed that random (r = -.49) and canonical (r = - .48) dot enumeration inverse efficiency scores are explained by mathematics achievement scores (F (4, 16) = 4.81, p = .016). Problem-solving abilities, on the other hand, did not predict enumeration performance. Thus, students who had lower executive functions, working memory, and mathematics achievement had longer

response times in the random dot counting task both in number sense tests and during the activities within Minecraft .

The first important finding is that general cognitive abilities which are inhibitory control, attention, and visual-spatial memory predicted enumeration performances in canonically and randomly displaced dot arrays. Among inhibitory control (r = -.26) and visual-spatial span (r = -.23), attention (r = .39) uniquely predicted canonical dot enumeration skills (F (4, 16) = 4.81, p = .016). The visual-spatial span (r = -.41) predicted random dot enumeration over and above inhibitory control (r = -.28) and attention (r = .27) (F (4, 16) = 4.81, p = .016).

Notably, among executive functions, attentional control measures were the most predictive for dot enumeration performances. These results consistent with the previous literature that subitizing and counting require considerable attentional effort (Olivers & Watson, 2008). Additionally, enumeration of randomized and canonical dot patterns requires attention (Briggs, Wasylyshyn, & Bello, 2020), and attentional need increases as the number of objects increases (Railo, Koivisto, Revonsuo, & Hannula, 2008). Railo et al. (2008, p.102) state that subitizing process includes recognition of similar pattern and load to visual-short term memory, however; enumeration of larger sets requires object tracking, continuous attention, and updating the contents to short term memory.

The findings of this study showed that attentional control demand of enumerating randomly placed dot arrays is high. This suggests that canonical dot arrays require less attentional resources as recognition of similar patterns reduced the need for object tracking (i.e., inhibition) and continuous attention in subitizing 1-4 objects. A similar pattern identification probably required less update; therefore,

visuospatial short-term memory demands of the canonical dot enumeration was less than random-dot enumeration.

The qualitative findings also supported that when students performed enumeration in video game tasks, they made more enumeration errors on tasks where objects were randomly placed. Therefore, attentional control becomes more critical when enumerating larger and unfamiliar dot arrays. Action video games are widely acknowledged as improving attentional control, requiring continuous selective attention to the stimuli (Bediou, Bavelier, & Green, 2021; Chisholm & Kingstone, 2015; Green, Gorman, & Bavelier, 2016). Furthermore, the quantitative results showed that students' enumeration errors decreased after the action video game intervention. Therefore, supporting the findings of this study, subitizing and counting require attentional control, and playing video games was most likely to improve those skills.

Additionally, children need selective eye movements and visual scanning when they enumerate, and the maximum capacity of enumeration is not reached before the age of 11 (Schleifer & Landerl, 2011). Wu and Spence (2013) found that playing action video games improved visual searching skills as well as divided attention. Importantly, qualitative findings revealed that students with low enumeration performances in BNPT made more errors during interviews when performing visual scanning. Accordingly, Minecraft enumeration tasks required students to be quick and carefully watch the screen and enumerate.

The enumeration performances are also controlled by working memory capacity. Visual-short term memory span explained variances in random-dot enumeration performance more than variances in canonical dot enumeration performance. The results consistent with the literature that students easily recognize

canonical arrays and similar patterns' memory load is low (Railo et al., 2008). The findings of this study showed that the visual-spatial memory demand of enumerating randomly placed dot arrays was high. Therefore, students' short-term memory span was more susceptible to unfamiliar dot arrays (i.e., randomly placed objects).

There is individual variability in dot enumeration performances of children, and shorter dot enumeration response times are indicators of higher mathematics ability (Gray & Reeve, 2014; Gray & Reeve, 2016; Major, Paul, & Reeve, 2017; Paul, Gray, Butterworth, & Reeve, 2019). Students with higher scores in the mathematics exam got lower performances in enumeration tasks. The results were consistent with the literature that higher-achieving students had shorter response times in canonical and randomly placed dot enumeration tests (Gray & Reeve, 2014; Major, Paul, & Reeve, 2017; Nguyen, M. & Nguyen, T., 2013).

As in Gray and Reeve's (2014) study, mathematics abilities predicted dot enumeration speeds beyond executive functions, which were inhibitory control, attention, and visuospatial memory. Moreover, Sowinski et al. (2015) explored the contribution of quantitative, linguistic, and working memory pathways on numerical development of second and third-grade children. They found that performances in subitizing, counting, and symbolic number comparison, referred to as quantitative pathways, uniquely explained variance in calculation and number system knowledge (Sowinski et al., 2015). Thus, findings of this study support that subitizing and counting are key abilities for numerical cognition of the child, and competencies in enumeration contribute to mathematics achievement beyond executive functions.

Last, inverse efficiency scores were calculated to combine speed and accuracy when determining dot enumeration performances (Bruyer & Brysbaert, 2011). The results were contradictory as students with lower dot enumeration

performances had higher scores in the problem-solving test. In addition, it was found that mathematics achievement uniquely predicted dot enumeration performances. Träff (2013) found that dot enumeration performances predicted competence in arithmetic skills from grade four to six (Traff, 2013). These findings suggested that problem-solving tests required more complex mathematical skills than simple arithmetic required in mathematics exams.

5.1.3 The role of executive functions, mathematics achievement, and problem-solving skills in explaining individual differences in mental number line performances

The 0-10, 0-100, and 0-1000 number line scores were measured by Basic Number Processing Test (BNPT) before and after the intervention. The first primary finding was that students' hundred and thousand number line estimates significantly improved after Minecraft number line tasks. Nonetheless, the pretest ten number line scores have not significantly differed from posttest scores. This is an important finding in understanding whether estimation competencies of the sample of this study (i.e., fourth graders) are parallel with the previous literature. Children's precisions in number line estimations improve with age, and fourth-graders 0-1000 number line estimation fit logarithmic models (Booth & Siegler, 2006; Siegler & Opfer, 2003).

The results showed that fourth graders in our study improved significantly in hundred and thousand number line estimations. In particular, the thousand number line estimates improved the most among all. The current findings confirmed that fourth graders are the least competent in estimating 0-1000, Minecraft video game instruction considerably improved their thousand number line skills (r = . 51). Additionally, the previous literature suggests that fourth-graders 0-100 estimation

skills were best fit linear model (Siegler & Opfer, 2003). The current findings suggested that students' hundred number line estimation skills also improved after Minecraft-hundred number line intervention. From the findings, it is clear that Minecraft number line games improve students' estimation skills.

It is acknowledged that number line estimation skills are highly predictive for arithmetic learning (Booth & Siegler, 2008; Gunderson, Ramirez, Beilock, & Levine, 2012; Yang & Yu, 2020) and mathematics achievement (Schneider, Grabner, & Paetsch, 2009; Siegler & Opfer, 2003). In addition, number line estimation skills are explained by individual differences in spatial skills (Gunderson, Ramirez, Beilock, & Levine, 2012; Yang & Yu, 2020) and visual-spatial working memory (). Furthermore, an fMRI study explored 8 to 14-year-old children's brain activation when performing mental number line estimation (Berteletti, Man, & Booth, 2015). The less competent children in number line estimation had small visual-spatial area activation compared to skilled estimators (Berteletti et al., 2015).

After video-game intervention, hundred and thousand mental number line scores were improved significantly. The number line gains were calculated by subtracting posttest and pretest number line scores. The hierarchical regression analysis revealed that mathematics achievement predicted ten number line gains (F (2, 18) = 5.42, p = .009, r = -.56) and thousand number line gains (F (1, 19) = 5.71, p = .039, r = .47). The mathematics exam grades and hundred number line scores were correlated; however, hundred number line gains could not be explained by mathematics achievement.

Only the ten number line gains were predicted by visual memory span (r = -. 16), and students with smaller memory span benefitted more from video game intervention. Along with the qualitative findings, the results implied that the

arithmetic abilities of students became a stronger predictor when the range of number lines increases. The results also demonstrated that the influence of visual-spatial memory span on number line gain was decreased from ten to thousand number lines. The qualitative findings supported that high achieving students used mathematical strategies such as rounding, proportional judgment, and arithmetics when performing hundred and thousand number line video game tasks. The qualitative finding showed that students with less competence in hundred and thousand number line scores were lack of those strategies. Therefore, the effect of arithmetic skills on mental number line judgment goes beyond general cognitive abilities as the mathematical complexity increased.

The number line video game activities were not improved only by low achievers; the game encouraged students to use mental arithmetic to find the location of numbers. Most of the students, including low achievers, attempted to use mental arithmetic when describing the location of numbers in thousand number line. However, the typical achievers and high achievers effectively used mental addition and subtraction to estimate the location of numbers.

In conclusion, the number line video game activities were supported the number line estimation skills of students with different competencies. However, estimation scores of less competent students were stayed below average in the hundred and thousand number line. The video game supported all students; however, mental arithmetic activities should be integrated to increase the effect of the Minecraft game.

5.1.4 The summary of the discussion

The findings of the study suggested that video games have the potential to improve the number sense abilities of children. Even though playing Minecraft enumeration tasks did not significantly improve overall dot enumeration performances, low achieving students considerably benefited from the instruction. The low achieving students decreased their dot enumeration inverse efficiency scores considerably, which implied that they enumerate faster and more accurately after the intervention.

Anobile (2013) et al. claimed that video games improve subitizing range and decrease enumeration response time. The current study did not specifically focus on subitizing range, but preliminary findings suggested that enumeration response times of low achieving students decreased. Further studies can explore the effect of Minecraft number sense game on subitizing and counting skills by assessing each individual dot array (i.e., 1-9 dots) separately to determine the change in the subitizing range and reaction times in that specific array. For example, the response time of the enumeration of eight dots should be measured before and after Minecraft dot enumeration intervention.

In contrast to dot enumeration performances of the participants, students' number line scores significantly improved after playing Minecraft number line tasks. These results showed that video games provide support for developing number line estimation skills. Moreover, low number line estimators improved the most after playing the video game, which implied that intervention provided strategies and skills for precise estimations.

5.2 Implications and future studies

Considering that educational research studies, there were no scientific studies investigating dot enumeration and mental number line ability improvement by designing a three-dimensional video game. Therefore, the research was a primary source in this context. The findings were promising that Minecraft number sense game had considerable potential to improve the number sense abilities of fourth graders.

Moreover, Minecraft number sense games should be employed to younger children particularly, second and third graders. The mouse-controlled version may not be appropriate for younger children because the game requires mouse skills. Joiner, Light, and Littleton (1998) found that speed and accuracy using mouse improves significantly from age four to age twelve with a declining trend after the age eight (as cited in Lane & Ziviani, 2010). Therefore, Minecraft number sense game should be employed in younger grades with a touch-screen version.

After the intervention, the group's dot enumeration performances measured by inverse efficiency scores were not improved. However, most participants considerably decreased response times and enumeration errors which implied improvement. Therefore, a larger sample is needed to have variation in scores.

The Minecraft mental number line tasks were designed to allow students to find the exact location of the numbers. Nonetheless, the qualitative findings and observations of video recordings implied that students need more scaffolding when playing the game. Kermani (2017) suggested that computer games became effective tools merely as an adult or the teacher scaffold the children. The feedbacks helped locate the numbers; however, some students had difficulty playing hundred and

thousand tasks. The current study found that the game needed more support for hundred and thousand number line tasks.

Therefore, the outcomes of this study support the notion that students were most likely to benefit from the Minecraft game instruction when they are played under adult supervision. In particular, challenging levels may need more support than others.

The estimation error rates demonstrate the competency in estimating a specific number and decrease in estimation error rates implies improvement (Siegler and Opfer, 2003; Booth and Siegler, 2006). The estimation errors of each number line range should be calculated separately, before and after the intervention, to evaluate the effect of the game on specific numbers.

Additionally, a more extended implementation duration is suggested for both enumeration and number line games. Qualitative findings revealed that low attainers had difficulty enumerating during the game. Therefore, the larger sample will be more representative to evaluate the effect of the game on learners from different levels.

5.3 Limitations

In this study, the sample size was limited and consisted of children from high SES. Unfortunately, students from low SES are susceptible to low number sense abilities because of a lack of guidance from parents (Jordan, Glutting, Dyson, Hassinger-Das, & Irwin, 2012). The most underlying reason for low-income children's deficient number sense is insufficient educational support from their parents in terms of quantity and number (Liang, Zhang, Long, Deng, & Liu, 2020). Therefore, the study

should be replicated with larger samples, including participants from diverse SES, in particular, students from low-SES.

Additionally, the data was collected on account of the Covid-19 epidemic, and the interventions were remotely implemented. Some participants were excluded from the study because of technical problems with their computers. Screen recordings were collected to evaluate students' game experiences and to control over intervention. However, the field observations of the researcher regarding the game and student interaction were lacking. Therefore, implementing the study in the school environment is needed to validate the data and eliminate data loss.

The dot enumeration performances of the students were measured by completion time, which limited the evaluation of the effect of the video game on subitizing range and response times. It is needed to measure subitizing range and response times to explore the potential of Minecraft videogame on the subitizing range.

APPENDIX A

BASIC NUMBER PROCESSING TEST (Reduced Sample)

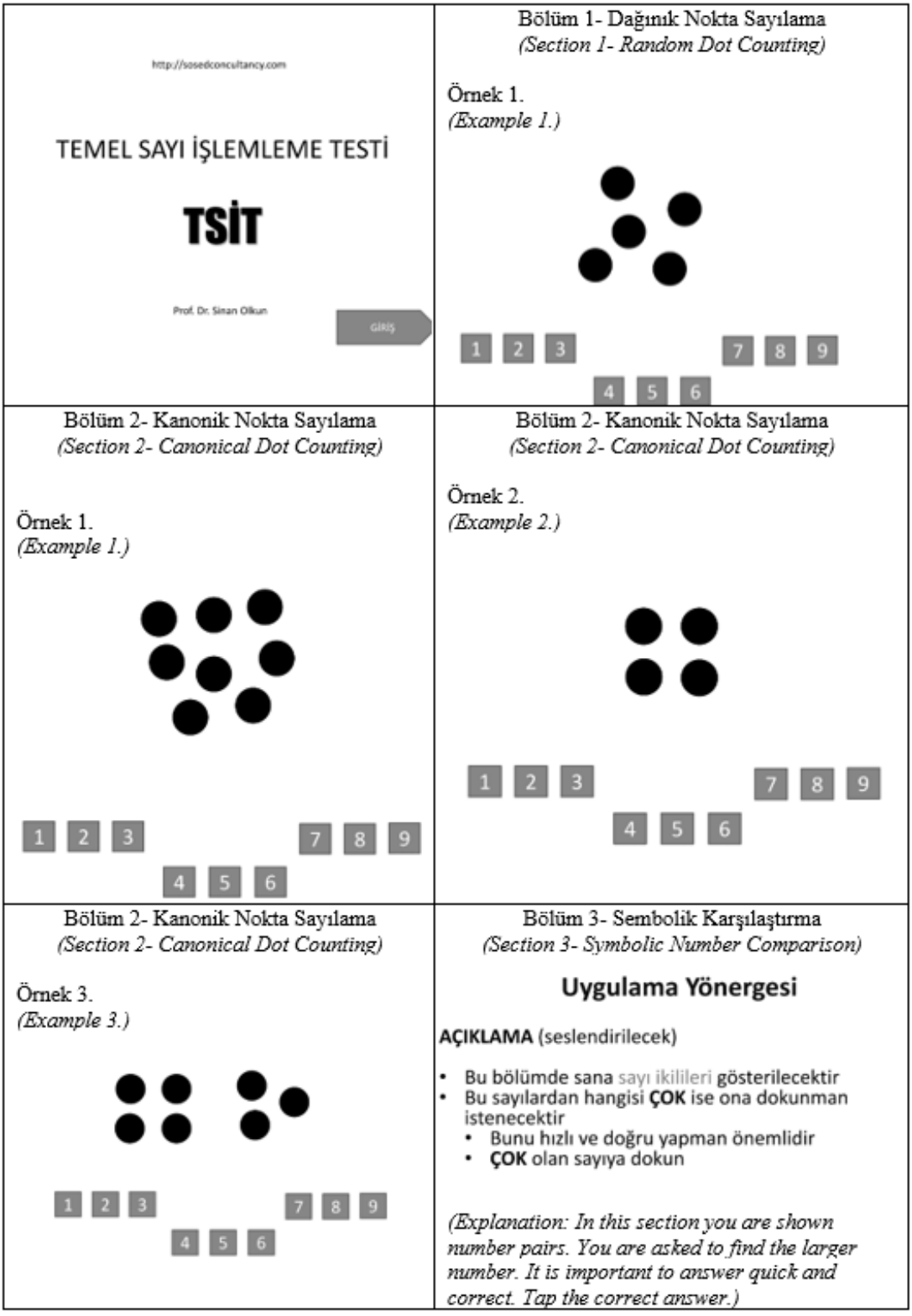


Figure A1. BNPT dot enumeration sample questions

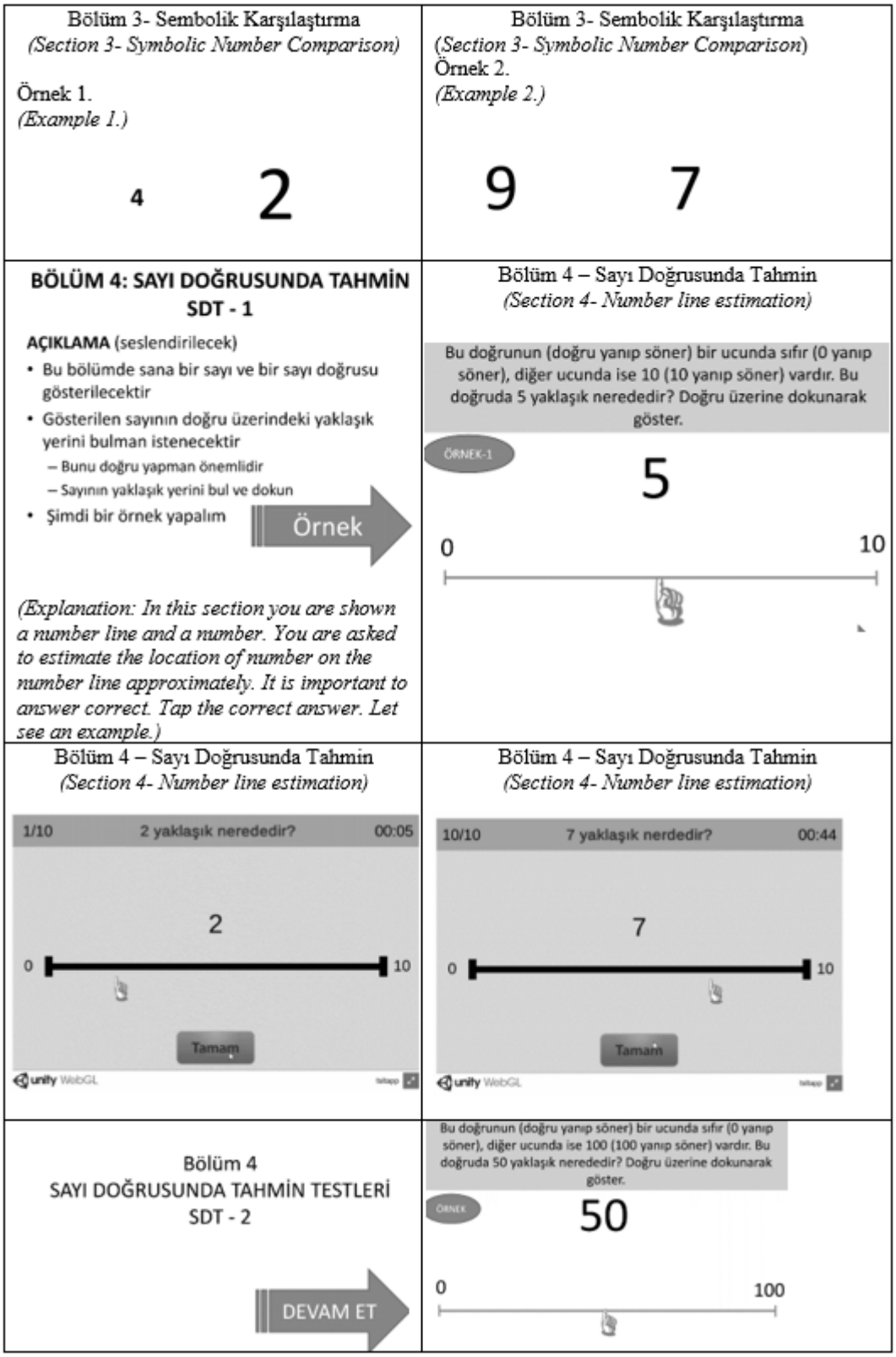


Figure A2. BNPT mental number line estimation sample questions

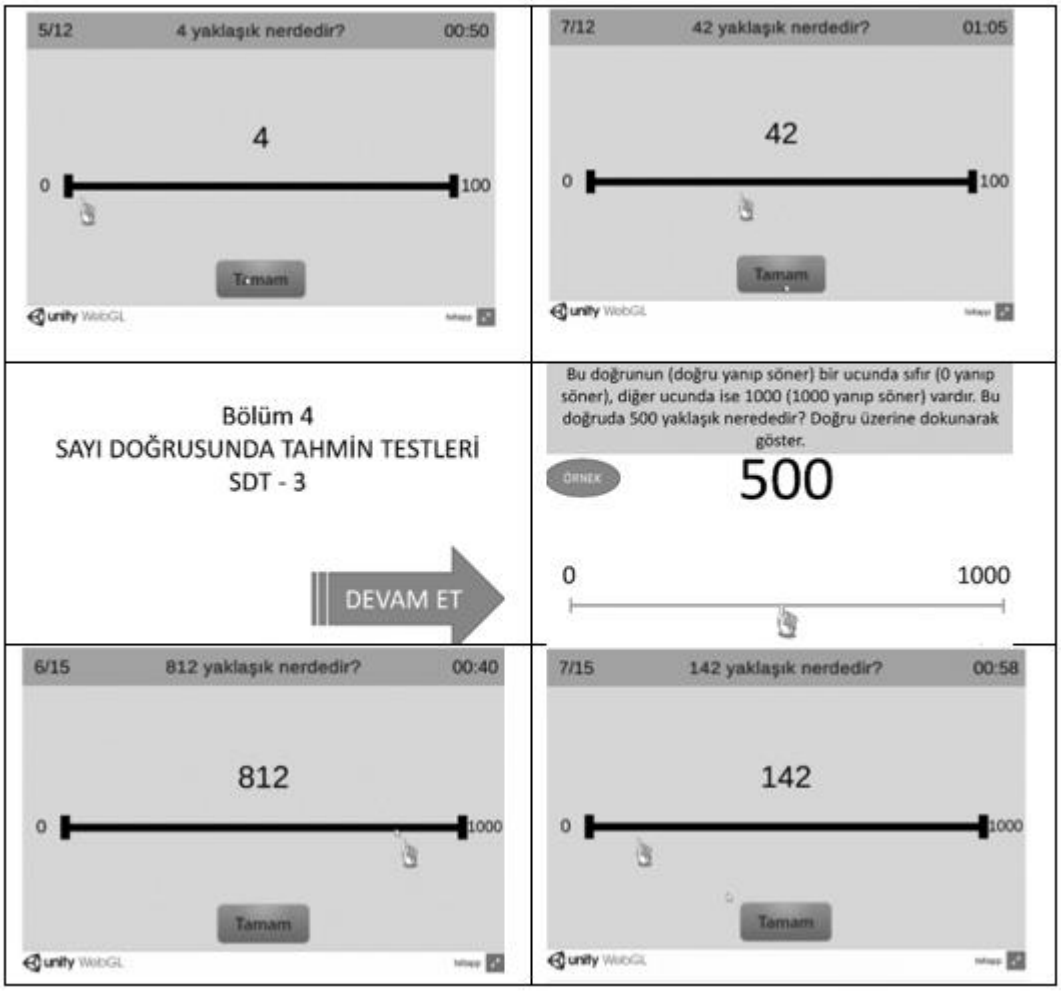


Figure A3. BNPT thousand number line estimation sample questions

APPENDIX B

WORKING MEMORY BATTERY



Figure B1. Stroop task

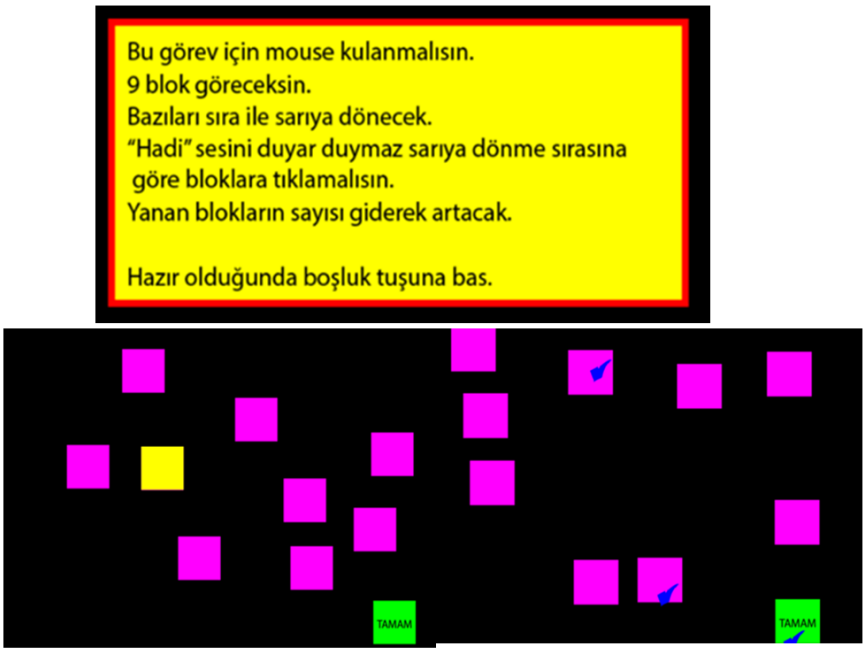


Figure B2. Corsi task

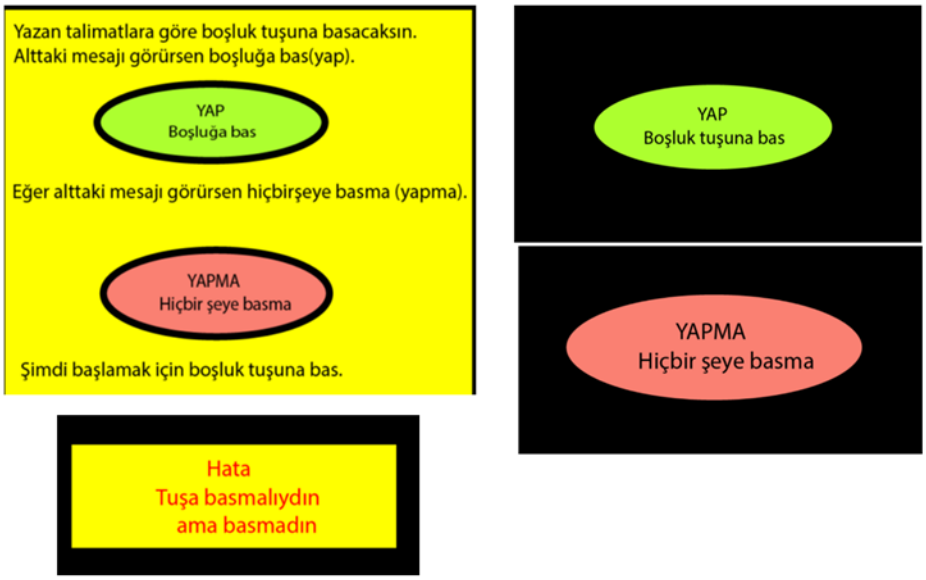


Figure B3. Go-no/go task

APPENDIX C

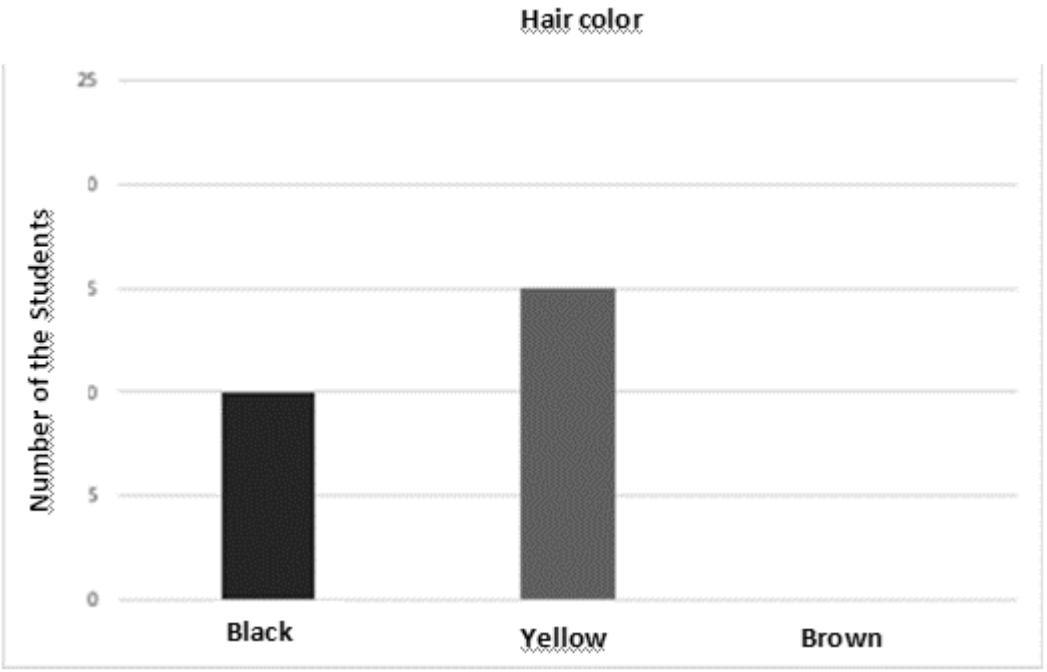
PROBLEM SOLVING TEST

Name: _____ Birthdate:_____

Problem Solving Test and Scoring Guide

Dear students, thank you very much for answering the following questions with all your attention and sincerity and contributing to our work.
Doç. Dr. Serkan Özel

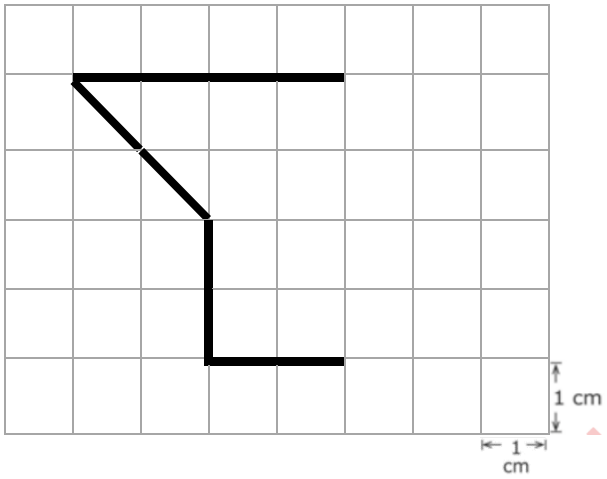
1. In a class of 30 students, 10 have black hair,15 have blonde hair, and the rest have brown hair. Complete the graph below to show the number of students with brown hair.



(TIMMS, 2003)

Code	Answer	Item: 1
	Correct Answer	
10	Bar for brown hair drawn to the horizontal line at 5	
	Incorrect Answer	
79	Other incorrect (including crossed out, erased, stray marks, illegible or off task)	
	NonResponse	
99	Blank	

2.



The squares in the grid above have areas of 1 square centimeter. Draw lines to complete the figure so that it has an area of 13 square centimeters.

(TIMMS, 2003)

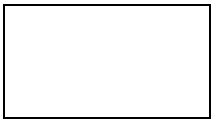
Code	Answer	Item: 2
	Correct Answer	
10	Lines drawn to give area of 13 square cm	
	Incorrect Answer	
70	Error due to counting half squares as full square centimeters	
71	One line drawn to close given figure	
72	Symmetrical figure drawn	
79	Other incorrect	
	NonResponse	
99	Blank	

3. Answer following questions.

A. Draw 1 straight line on this rectangle to divide it into 2 triangles.



B. Draw one straight line on this rectangle to divide it into 2 rectangles.



C. Draw 2 straight lines on this rectangle to divide it into 1 rectangle and 2 triangles.

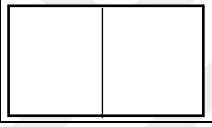


(TIMMS, 2003)

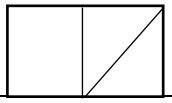
A: Making 2 Triangles

Code	Answer	Item: 3A
	Correct Answer	
10	One diagonal drawn 	
	Incorrect Answer	
70	One horizontal or vertical line drawn	
79	Other incorrect	
	NonResponse	
99	Blank	

B: Making 2 Rectangles

Code	Answer	Item: 3B
	Correct Answer	
10	One horizontal or vertical line drawn 	
	Incorrect Answer	
70	One diagonal drawn	
79	Other incorrect	
	NonResponse	
99	Blank	

C: Making 1 Rectangle and 2 tr

Code	Answer	Item: 3C
	Correct Answer	
10	Two lines correctly drawn to show a smaller rectangle and two rectangles 	
	Incorrect Answer	
70	Attempt made with two lines drawn but drawing does not show a line dividing the rectangle into 2 rectangles with a diagonal accurately drawn in one of them.	
79	Other incorrect	
	NonResponse	
99	Blank	

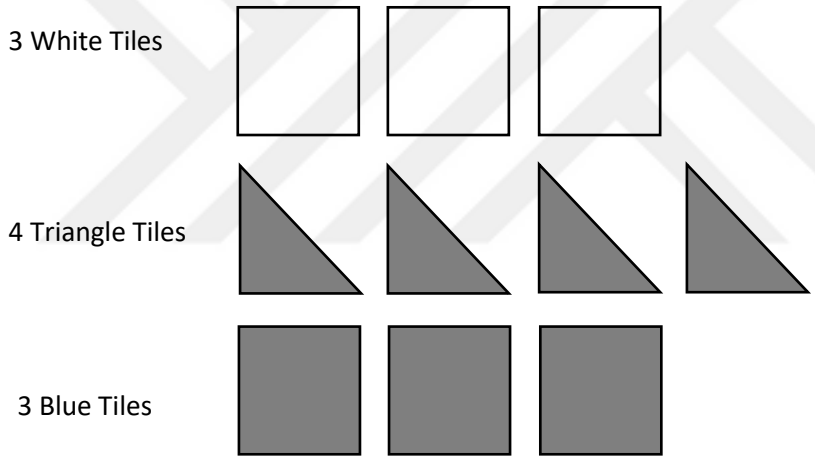
4. Burak thought of a number. He then multiplied it by 2 and added 4. The answer Burak obtained was 16. What was the number he first thought of?

Answer: _____

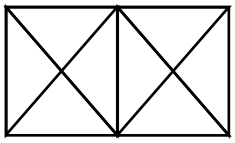
(TIMMS, 2003)

Code	Answer	Item: 4
	Correct Answer	
10	6	
	Incorrect Answer	
70	2, 4, 10	
79	Other incorrect	
	NonResponse	
99	Blank	

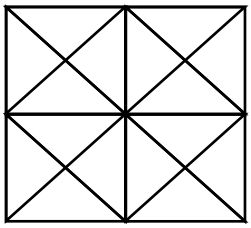
5. For these questions, you are given 10 tiles.



A. Construct a larger triangle using 2 of the triangles. Then show the triangle you created with these triangles by painting it on the figure below.



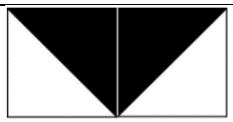
B. Create a square using all 4 triangles. Then show the square you created with these triangles by painting it on the figure below.



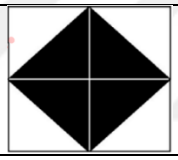
C. Write down the fraction that corresponds to the painted parts of the shape you created in question B.

Answer: ……

A: Codes for Triangle Pattern

Code	Answer	Item: 5A
	Correct Answer	
10	 or 	
	Incorrect Answer	
70	Creating two small triangles using two triangles	
79	Other incorrect	
	NonResponse	
99	Blank	

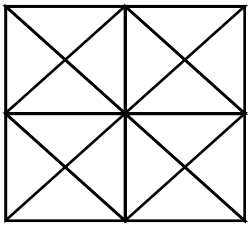
B: Codes for Square Pattern

Code	Answer	Item: 5B
	Correct Answer	
10		
	Incorrect Answer	
70	Using four triangles but not getting the black square. 	
79	Other incorrect	
	NonResponse	
99	Blank	

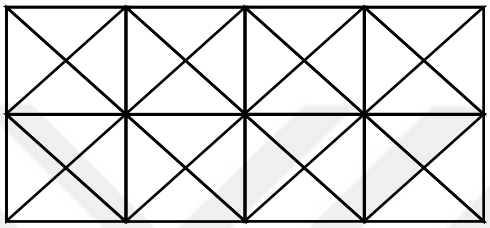
C: Codes for fraction

Code	Answer	Item: 5C
	Correct Answer	
10	1/2 or equal fraction	
11	Finding correct ratio by using incorrect pattern in option B.	
	Incorrect Answer	
70	1/4 or equal fraction	
79	Other incorrect	
	NonResponse	
99	Blank	

D. WITHOUT using triangular tiles, place 4 tiles so that ½ of the figure below is painted. Then show the shape you created by painting it on the figure below.

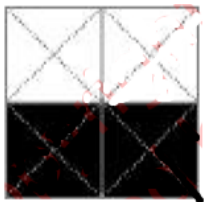


E. Using 8 tiles, make sure that 5/8 of the figure below is painted. Then show the shape you created by painting it on the figure below.

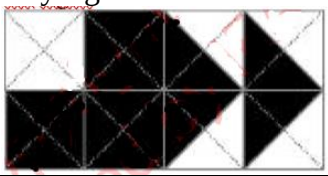


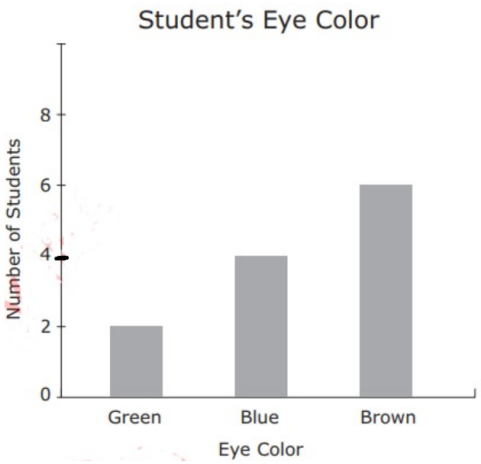
(TIMMS, 2003)

D: Codes for 4-Tiles pattern without triangles

Code	Answer	Item: 5D
	Correct Answer	
10	Creating the pattern using 2 black tiles and 2 white tiles. See the examples below.  or 	
	Incorrect Answer	
70	Shading 1/2 of it but using triangular tiles	
71	Shading 1/4 of the shape	
72	Shading 3/4 of the shape	
79	Other incorrect	
	NonResponse	
99	Blank	

E: Codes for 8-Tiles Pattern

Code	Answer	Item: 5E
	Correct Answer	
20	Any figure that can be created using 3 black, 1 white and 4 triangular tiles: 	
	Partially Correct Answer	
10	Covering 5/8 of the shape without using correct tiles	
	Incorrect Answer	
70	Shading 1/2 of the shape	
79	Other incorrect	
	NonResponse	
99	Blank	



6. The chart above shows the eye color of all students in Ms. Züleyha's choir.
   A. How many students are in Ms. Züleyha's choir?
      Answer: …….

   B. What fraction of Ms. Züleyha's choir has blue eyes?
      Answer: …….

(TIMMS, 1999)

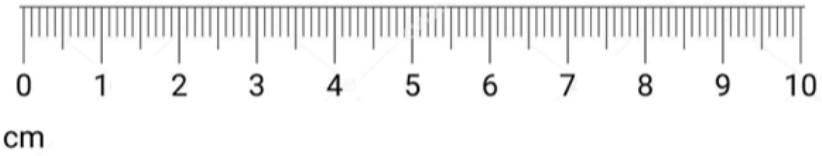
A: Finding the exact value of data given on bar graph

Code	Answer	Item: 6A
	Correct Answer	
10	12	
	Incorrect Answer	
79	Other incorrect	
	NonResponse	
99	Blank	

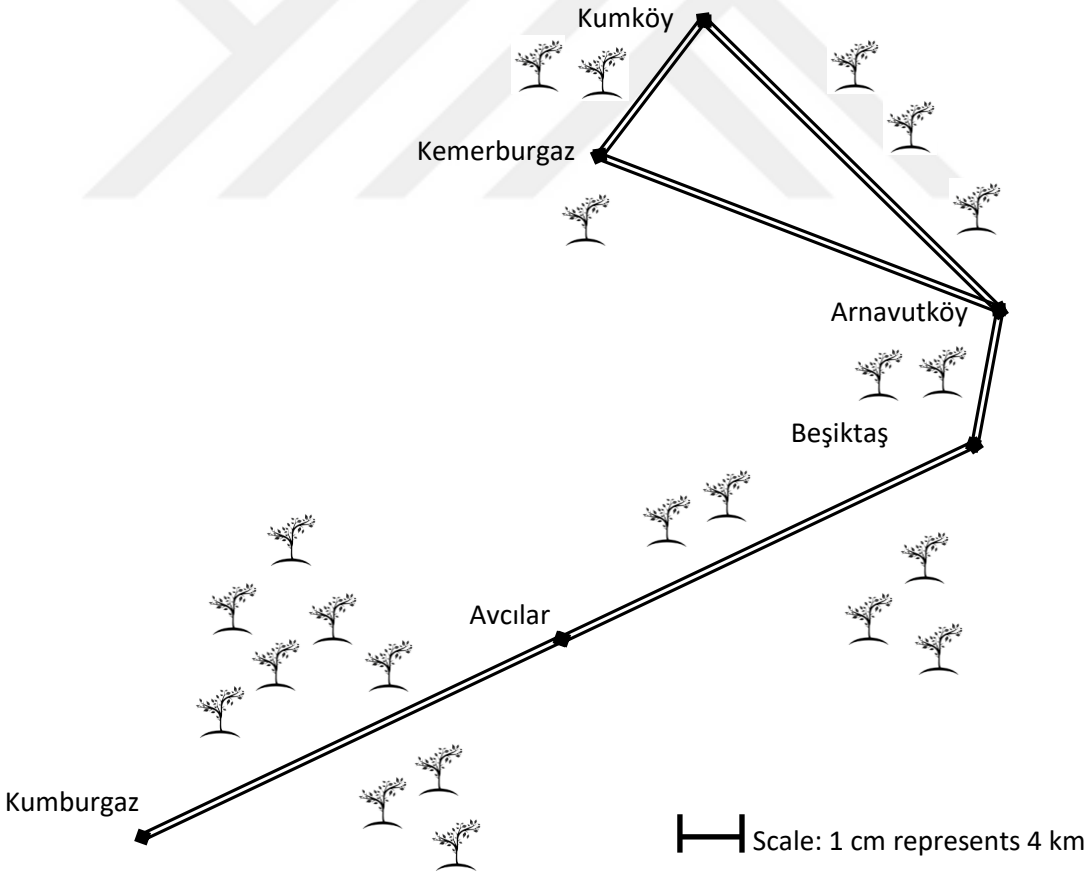
B: Finding the ratio of data to whole given on bar graph

Code	Answer	Item: 6B
	Correct Answer	
10	4/12 or equal fractions	
	Incorrect Answer	
79	Other incorrect	
	NonResponse	
99	Blank	

7. For these questions, you have been given a cardboard ruler.



Use the map below and your ruler to answer this set of questions.



Traveling Between Towns

A. How many centimeters is it between Kumburgaz and Beşiktaş on the map?

Answer: …… centimeters (cm)

B. How many kilometers is it between Kumburgaz and Beşiktaş on the road?

Answer: …… kilometre (km)

C. It takes one hour to drive from Kumburgaz through Avcılar to Beşiktaş. At the same speed, how much time would it take to travel from Kumburgaz to Avcılar?

Answer: …….

(TIMMS, 1999)

Code	Answer	**Item: 7A**
	Correct Answer	
10	15	
	Incorrect Answer	
71	Incorrect ölçüm	
79	Other incorrect (including crossed out, erased, stray marks, illegible or off task)	
	NonResponse	
99	Blank	

Code	**Answer**	**Item: 7B**
	Correct Answer	
10	60	
11	Four times of previous incorrect answer	
	Incorrect Answer	
79	Other incorrect (including crossed out, erased, stray marks, illegible or off task)	
	NonResponse	
99	Blank	

Code	**Answer**	**Item: 7C**
	Correct Answer	
10	30 minutes	
	Incorrect Answer	
79	Other incorrect (including crossed out, erased, stray marks, illegible or off task)	
	NonResponse	
99	Blank	

Distance from Arnavutköy (TIMMS, 2003)

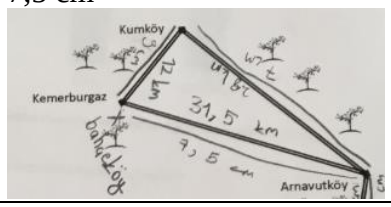
D. Is Kemerburgaz or Kumköy closer to Arnavutköy?
Answer: ……

E. How many centimeters closer is it on the map?
Answer: …….. centimeters (cm)

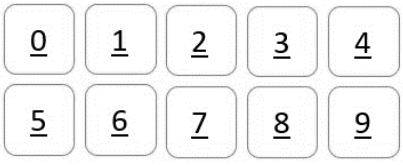
F. Another town called Bahçeköy is the same distance from Arnavutköy as it is from Kumburgaz. Show on the map where Bahçeköy might be located. Mark it with an X and write Bahçeköy below it.

Code	Answer	Item: 7D
	Correct Answer	
10	Kumköy	
	Incorrect Answer	
79	Other incorrect	
	NonResponse	
99	Blank	

Code	Answer	Item: 7E
	Correct Answer	
10	0,5 cm or half centimeter	
	Incorrect Answer	
79	Other incorrect	
	NonResponse	
99	Blank	

Code	Answer	Item: 7F
	Correct Answer	
10	7,5 cm 	
	Incorrect Answer	
79	Other incorrect	
	NonResponse	
99	Blank	

8. For this item, you have been given a piece of cardboard with 10 square number tiles like ones shown below.



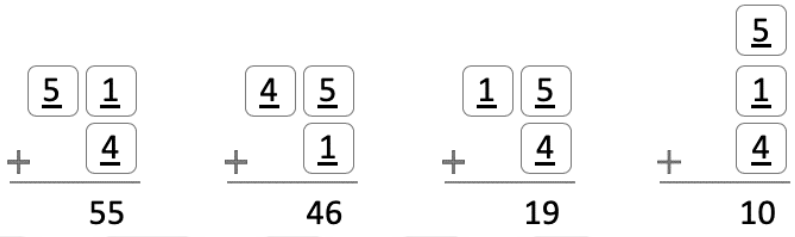
Get to 20

Two children, Elif and Emre, are learning to play a game "Get to 20". Here are the rules for the game.

Pick Tiles: Each player draws three number tiles.

Add Tiles: Each player places the three tiles to make an addition problem with the sum total closest to 20.

For example, here are four ways a player who draws 1, 4, and 5 could place the tiles:

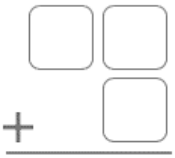


This player should choose to show addition problem  because 19 is the total closest to 20.

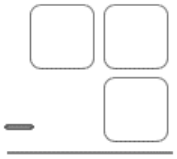
Find the Largest Number Game

Using the number tiles, Elif and Emre played a new game. They placed the numbers to make the largest answer.

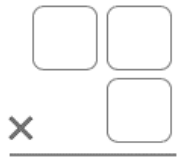
A. Use the tiles 1,5 and 9. Write the numbers on the tiles in the boxes below to make the largest answer when you add.



B. Use the tiles 2, 3 and 9. Write the numbers on the tiles in the boxes below to make the largest answer when you subtract.



C. Use the tiles 1, 4 and 5. Write the numbers on the tiles in the boxes below to make the largest answer when you multiply.



(TIMMS, 2003)

A: Getting the largest number by arranging certain numbers when performing addition.

Code	Answer	Item: 8A
	Correct Answer	
10	91 + 5 or 95+1	
11	Writing 91 + 5 or 95+1, however; the result of addition incorrectly.	
	Incorrect Answer	
70	Other combinations of 1, 5 ve 9 numbers.	
79	Other incorrect	
	NonResponse	
99	Blank	

B: Getting the largest number by arranging certain numbers when performing subtraction.

Code	Answer	Item: 8B
	Correct Answer	
10	93-2	
11	Writing 93-2, however; the result of subtraction incorrectly.	
	Incorrect Answer	
70	92-3	
71	Other combinations of 2, 3 ve 9 numbers.	
79	Other incorrect	
	NonResponse	
99	Blank	

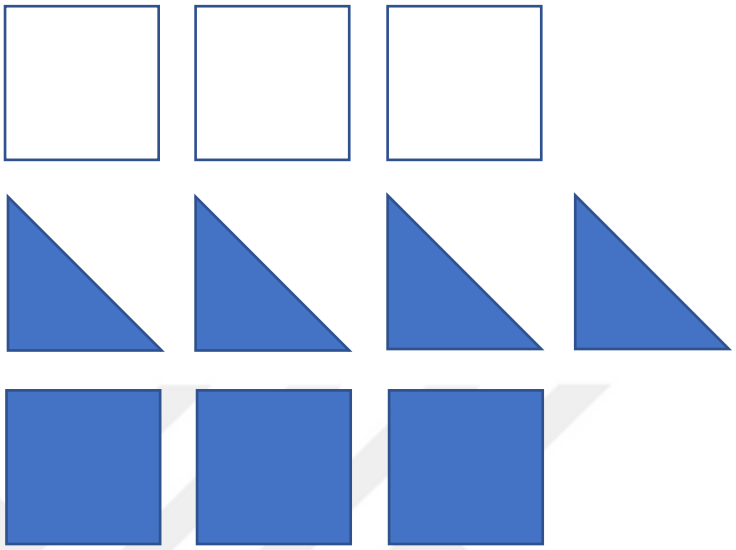
C: Getting the largest number by arranging certain numbers when performing multiplication.

Code	Answer	Item: 8C
	Correct Answer	
10	41 x 5	
11	Writing 41 x 5, however; the result of multiplicaiton incorrectly.	
	Incorrect Answer	
70	51 x 4	
71	Other combinations of 1, 4 ve 5 numbers.	
79	Other incorrect	
	NonResponse	
99	Blank	

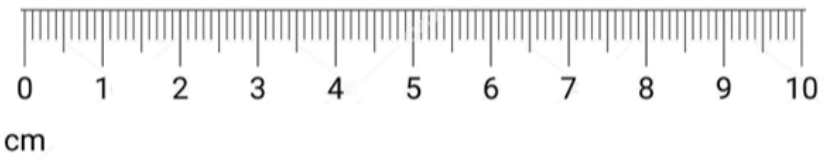
MATERIALS TO BE USED WHEN SOLVING QUESTIONS

The materials given here have been cut by the students and prepared to be used for the relevant question.

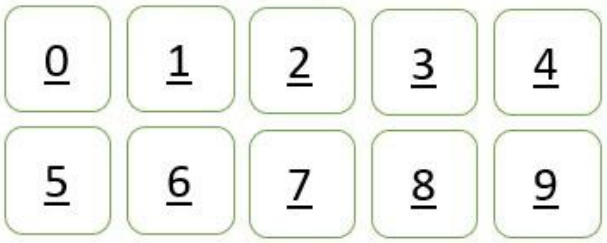
Question 5:



Question 7:



Question 8:



APPENDIX D

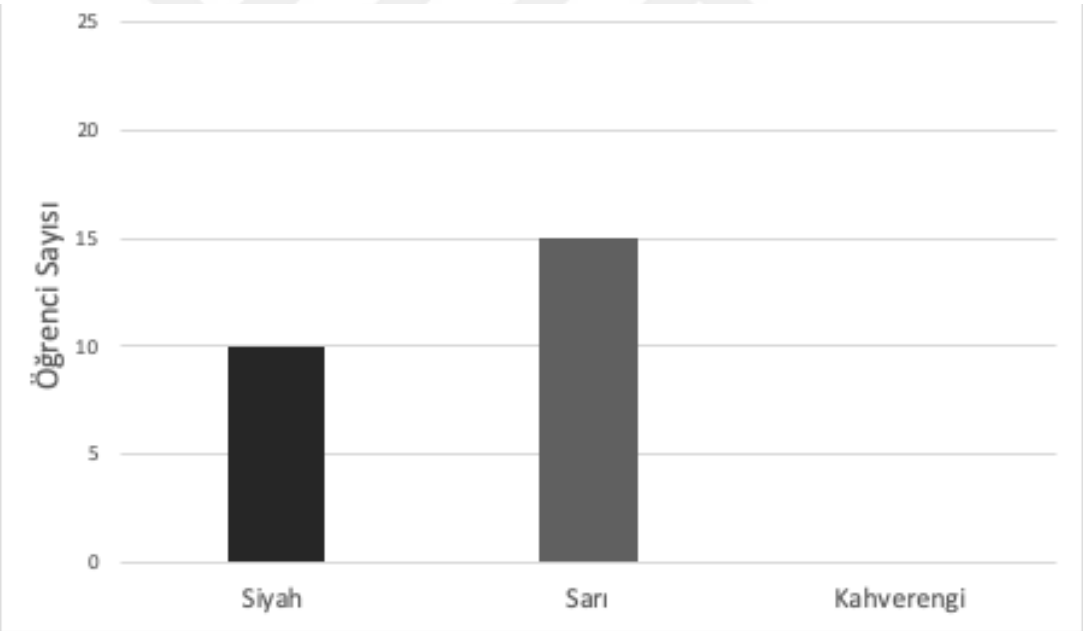
TURKISH VERSION OF PROBLEM SOLVING TEST

Ad-Soyad: _____ Doğum Tarihi:_____

Problem Çözme Testi ve Puanlama Klavuzu

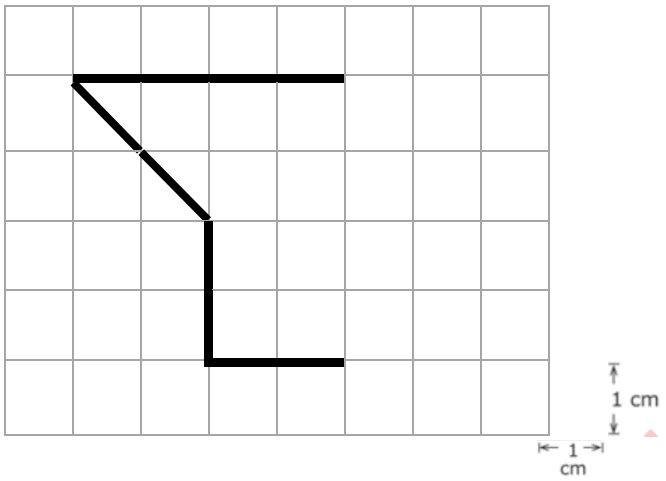
Sevgili öğrenciler, aşağıdaki soruları tüm dikkatiniz ve içtenliğinizle cevapladığınız ve çalışmamıza katkı sağladığınız için hepinize çok teşekkür ederiz.
Doç. Dr. Serkan Özel

1. 30 kişilik bir sınıfta 10 kişi siyah saçlı, 15 kişi sarı saçlı ve geri kalanları da kahverengi saçlıdır. Aşağıdaki grafiği tamamlayınız. (TIMMS, 2003)



Kod	Cevap	Madde: 1
	Doğru Cevap	
10	5 yatay çizgisine kadar çizilmiş sütun	
	Yanlış Cevap	
79	Diğer tür yanlışlar (üstü çizili / silinmiş, rastgele koyulmuş işaretler, okunaksız veya konu dışı)	
	Cevaplanmamış	
99	Boş	

2.



Yukarıdaki şekildeki her bir kare 1 santimetrekaredir. Alanı 13 santimetrekare olacak şekilde şekli çizgiler kullanarak tamamlayınız. (TIMMS, 2003)

Kod	**Cevap**	**Madde: 2**
	Doğru Cevap	
10	13 birimkareye tamamlayacak doğru parçalarının çizilmesi	
	Yanlış Cevap	
70	Yarım kareleri tam kare olarak sayma hatasından kaynaklanan yanlış	
71	Bir doğru parçasının şekli kapatmak için çizilmesi	
72	Şeklin simetrik görüntüsünün çizilmesi	
79	Diğer tür yanlışlar	
	Cevaplanmamış	
99	Boş	

3. Aşağıdaki 3 soruyu cevaplayınız.

A. Aşağıdaki dikdörtgenden, üzerine 1 doğrusal çizgi çizerek 2 üçgen oluşturun.



B. Aşağıdaki dikdörtgenden, üzerine 1 doğrusal çizgi çizerek 2 dikdörtgen oluşturun.



C. Aşağıdaki dikdörtgenden, üzerine 2 doğrusal çizgi çizerek 1 dikdörtgen ve 2 üçgen oluşturun.

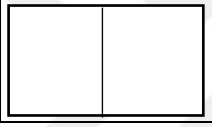


(TIMMS, 2003)

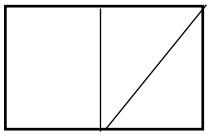
A: İki üçgen oluşturma görevi için kodlar

Kod	Cevap	Madde: 3A
	Doğru Cevap	
10	Bir köşegenin çizilmesi 	
	Yanlış Cevap	
70	Yatay veya dikey doğru parçasının çizilmesi	
79	Diğer tür yanlışlar	
	Cevaplanmamış	
99	Boş	

B: İki dikdörtgen oluşturma görevi için kodlar

Kod	Cevap	Madde: 3B
	Doğru Cevap	
10	Bir dikey veya yatay doğru parçasının çizilmesi 	
	Yanlış Cevap	
70	Yatay veya dikey çizginin çizilmesi	
79	Diğer tür yanlışlar	
	Cevaplanmamış	
99	Boş	

C: Bir dikdörtgen ve iki üçgen oluşturma görevi için kodlar

Kod	Cevap	Madde: 3C
	Doğru Cevap 	
10	Daha küçük olan dikdörtgeni ve iki üçgeni göstermek için iki doğru parçasının doğru olarak çizilmesi	
	Yanlış Cevap	
70	İki doğru parçasının çizilmesi ancak çizgilerin iki dikdörtgen ve köşegen çizilerek ulaşılan üçgeni göstermemesi	
79	Diğer tür yanlışlar	
	Cevaplanmamış	
99	Boş	

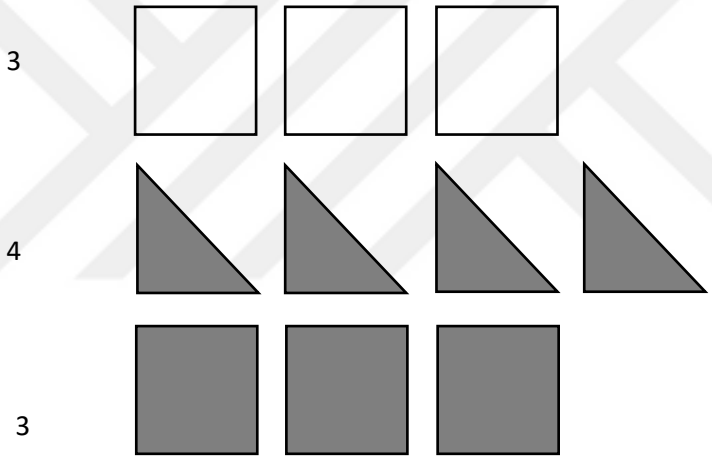
4. Burak aklında bir sayı tutmuştur. Daha sonra bu sayıyı 2 ile çarpıp 4 eklemiştir. Burak'ın elde ettiği sonuç 16'dır. Burak'ın tuttuğu ilk sayı kaçtır? İşlemlerinizi de gösteriniz.

Cevap: _____

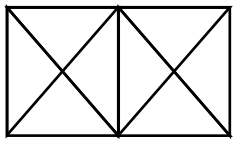
(TIMMS, 1999)

Kod	Cevap	Madde: 4
	Doğru Cevap	
10	6	
	Yanlış Cevap	
70	2, 4, 10	
79	Diğer tür yanlışlar	
	Cevaplanmamış	
99	Boş	

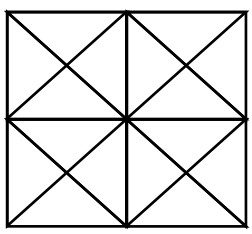
5. Bu soru için size aşağıda gösterilen gibi 10 kare verilmiştir. (TIMMS, 2003)



A. Üçgenlerden 2 tanesini kullanarak daha büyük bir üçgen oluşturun. Daha sonra bu üçgenlerle oluşturduğunuz üçgeni aşağıdaki şekil üzerinde boyayarak gösteriniz.



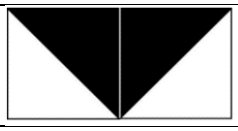
B. Üçgenlerin 4 tanesini de kullanarak bir kare oluşturun. Daha sonra bu üçgenlerle oluşturduğunuz kareyi aşağıdaki şekil üzerinde boyayarak gösteriniz.



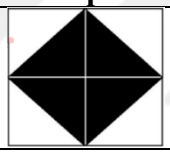
C. B şıkkındaki soruda oluşturduğunuz şeklin boyalı kısımlarına karşılık gelen kesri yazın.

Cevap: ……

A: Üçgen örüntüsü için kodlar

Kod	Cevap	Madde: 5A
	Doğru Cevap	
10	 ya da 	
	Yanlış Cevap	
70	İki üçgen kullanarak iki küçük üçgen elde edilmesi	
79	Diğer tür yanlışlar	
	Cevaplanmamış	
99	Boş	

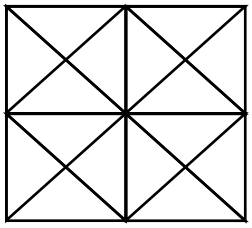
B: Kare örüntüsü için kodlar

Kod	Cevap	Madde: 5B
	Doğru Cevap	
10		
	Yanlış Cevap	
70	 Dört üçgenin kullanılması ancak siyah karenin elde edilmemesi	
79	Diğer tür yanlışlar	
	Cevaplanmamış	
99	Boş	

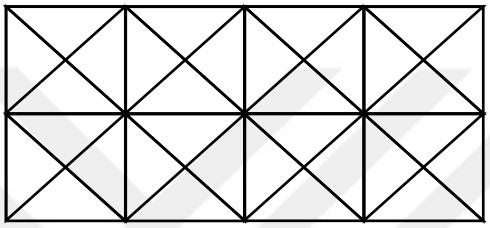
C: Şekil örüntüsünün kesri için kodlar

Kod	Cevap	Madde: 5C
	Doğru Cevap	
10	1/2 ya da denk kesri	
11	B sorusunun yanlış cevabındaki şekli kullanarak doğru cevaplanması	
	Yanlış Cevap	
70	1/4 ya da denk kesri	
79	Diğer tür yanlışlar	
	Cevaplanmamış	
99	Boş	

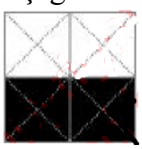
D. Üçgen karoları KULLANMADAN 4 karo yerleştirerek aşağıdaki şeklin ½'nin boyalı olmasını sağlayın. Daha sonra oluşturduğunuz şekli aşağıdaki şekil üzerinde boyayarak gösteriniz.



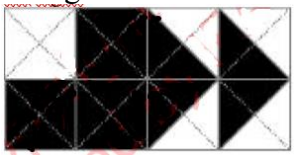
E. 8 karo kullanarak aşağıdaki şeklin 5/8'inin boyalı olmasını sağlayın. Daha sonra oluşturduğunuz şekli aşağıdaki şekil üzerinde boyayarak gösteriniz.



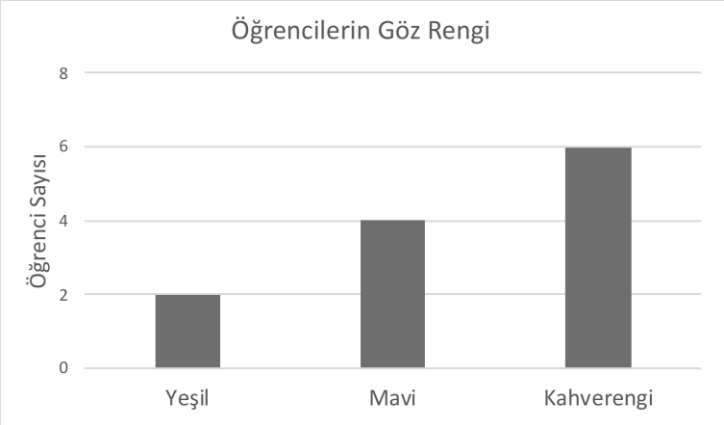
D: Üçgenler olmadan 4-Karo örüntüsü için kodlar

Kod	**Cevap**	**Madde: 5D**
	Doğru Cevap	
10	2 siyah karoyu ve 2 beyaz karoyu kullanarak örüntünün oluşturulması. Aşağıdaki örneklere bakınız.  ya da 	
	Yanlış Cevap	
70	1/2 'sinin taranması ancak üçgen karoların kullanılması	
71	1/4 'ünün taranması	
72	3/ 4' ünün taranması	
79	Diğer tür yanlışlar	
	Cevaplanmamış	
99	Boş	

E: 8-Karo örüntüsü için kodlar

Kod	**Cevap**	**Madde: 5E**
	Doğru Cevap	
20	3 siyah, 1 beyaz ve 4 üçgen karoyu kullanarak oluşturulabilecek herhangi bir figür: 	

	Kısmen Doğru Cevap
10	Doğru karoları kullanmadan şeklin 5/8'inin kaplanması
	Yanlış Cevap
70	1/2 'sinin taranması
79	Diğer tür yanlışlar
	Cevaplanmamış
99	Boş



6. Yukarıdaki grafik Züleyha Hanım'ın korosundaki öğrencilerin göz renklerini göstermektedir. (TIMMS, 1999)

A. Züleyha Hanım'ın korosunda kaç öğrenci vardır?

Cevap: …….

B. Züleyha Hanım'ın korosunun kaçta kaçının göz rengi mavidir?

Cevap: …….

A: Sütun grafiğinde verinin tam sayısını bulmak için kodlar

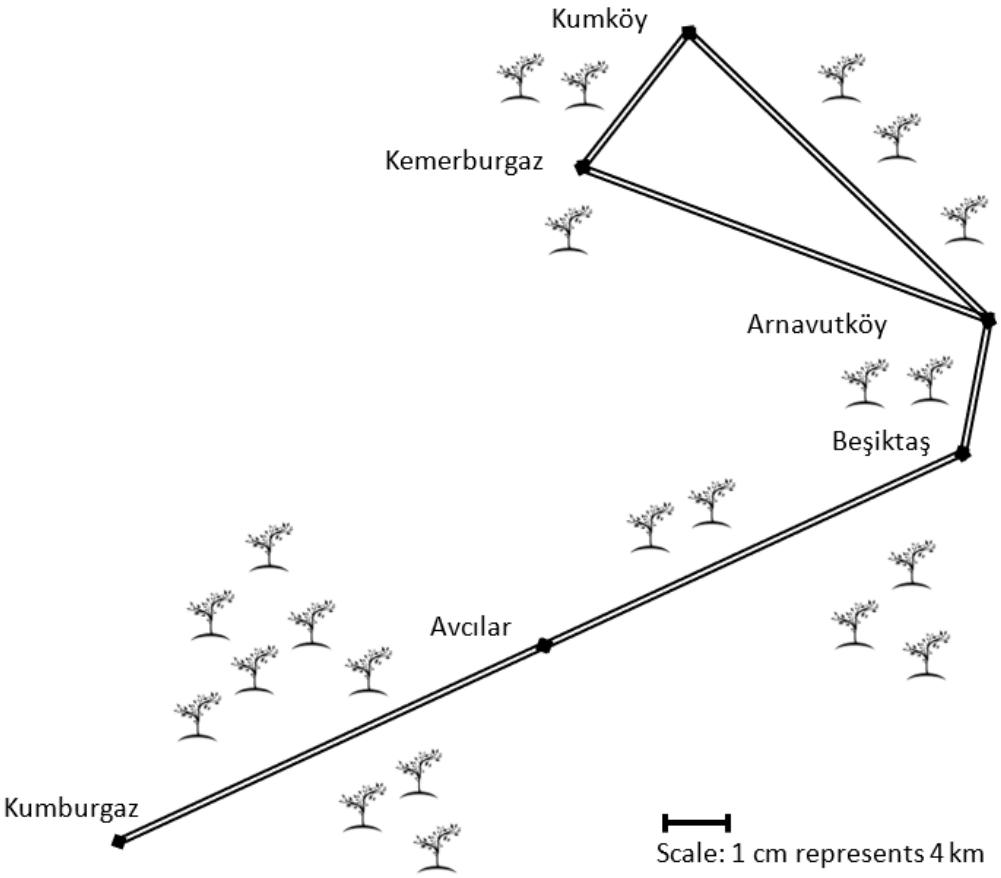
Kod	**Cevap**	**Madde: 6A**
	Doğru Cevap	
10	12	
	Yanlış Cevap	
79	Diğer tür yanlışlar (üstü çizili / silinmiş, rastgele koyulmuş işaretler, okunaksız veya konu dışı)	
	Cevaplanmamış	
99	Boş	

B: Sütun grafiğinde bir veri grubunun tüm veriye oranını belirlemek için kodlar

Kod	Cevap	Madde: 6B
	Doğru Cevap	
10	4/12 (12'de 4'ü) veya denk kesirler	
	Yanlış Cevap	
79	Diğer tür yanlışlar (üstü çizili / silinmiş, rastgele koyulmuş işaretler, okunaksız veya konu dışı)	
	Cevaplanmamış	
99	Boş	

7. Aşağıdaki sorular için size verilen karton cetveli kullanınız.

Soruları çözmek için aşağıdaki haritayı ve cetvelinizi kullanınız.



İlçeler Arası Seyahat

A. Kumburgaz ve Beşiktaş arası harita üzerinde kaç santimetredir?

Cevap: …… santimetre (cm)

B. Kumburgaz ve Beşiktaş arası kaç kilometredir?

Cevap: …… kilometre (km)

C. Kumburgaz'dan Beşiktaş'a, Avcılar üzerinden bir saatte gidiliyor. Aynı hızla, Kumburgaz'dan Avcılar'a ne kadar sürede gidilir?

Cevap: …….

(TIMMS, 1999)

Kod	Cevap	Madde: 7A
	Doğru Cevap	
10	15	
	Yanlış Cevap	
71	Yanlış ölçüm	
79	Diğer tür yanlışlar	
	Cevaplanmamış	
99	Boş	

Kod	Cevap	Madde: 7B
	Doğru Cevap	
10	60	
11	Önceki sorudaki yanlışın 4 katının bulunması	
	Yanlış Cevap	
79	Diğer tür yanlışlar	
	Cevaplanmamış	
99	Boş	

Kod	Cevap	Madde: 7C
	Doğru Cevap	
10	30 dakika	
	Yanlış Cevap	
79	Diğer tür yanlışlar	
	Cevaplanmamış	
99	Boş	

Arnavutköy'e Mesafeler

D. Arnavutöy'e, Kemerburgaz mı yoksa Kumköy mü daha yakın?

Cevap: ……

E. Harita üzerinde kaç santimetre daha yakın?

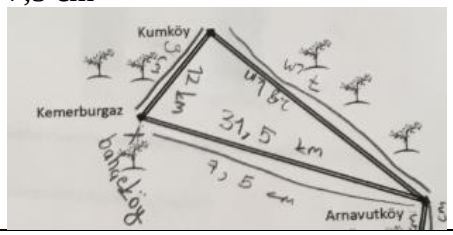
Cevap: …….. santimetre (cm)

F. Bahçeköy'ün Arnavutköy'e mesafesi Kemerburgaz'ın Arnavutköy'e mesafesi ile aynıdır. Bahçeköy'ün harita üzerinde nerede olabileceğini işaretleyin. X işareti koyun ve altına Bahçeköy yazın.

(TIMMS, 2003)

Kod	Cevap	Madde: 7D
	Doğru Cevap	
10	Kumköy	
	Yanlış Cevap	
79	Diğer tür yanlışlar	
	Cevaplanmamış	
99	Boş	

Kod	Cevap	Madde: 7E
	Doğru Cevap	
10	0,5 cm ya da yarım santimetre	
	Yanlış Cevap	
79	Diğer tür yanlışlar	
	Cevaplanmamış	
99	Boş	

Kod	Cevap	Madde: 7F
	Doğru Cevap	
10	7,5 cm 	
	Yanlış Cevap	
79	Diğer tür yanlışlar	
	Cevaplanmamış	
99	Boş	

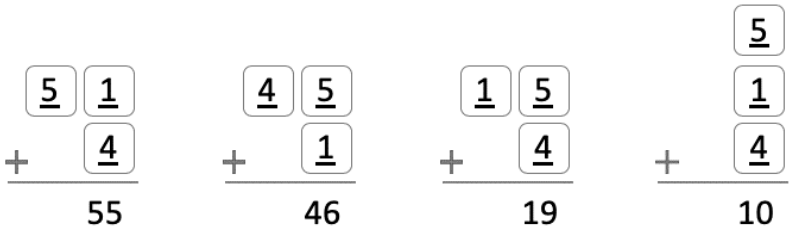
8. Bu soru için aşağıda gördüğünüz gibi üzerinde sayılar yazılı 10 kare verilmiştir.

YİRMİ OYUNU

İki çocuk, Elif ve Emre, birlikte "20 oyunu"nu oynuyorlar. Oyunun kuralları şu şekilde.

Kart Çek:	Her oyuncu üç kart çeker.
Kartları Topla:	Her oyuncu kartlarındaki sayıları toplamı 20'ye en yakın olacak şekilde toplama işlemi yapar.

Örneğin, elinde 1, 4 ve 5 kartları olan kişinin kartlarını yerleştirmesi için dört yol:



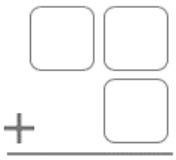


Bu oyuncu, toplamını seçmeli çünkü 20'ye en yakın toplam 19'dur.

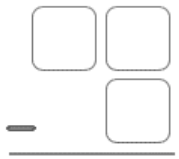
EN BÜYÜK SAYIYI BULMA OYUNU

Elif ve Emre, sayı kartları ile yeni bir oyun oynuyorlar. Bu oyunda en büyük sayıyı oluşturmaları gerekiyor.

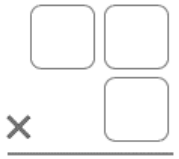
C. 1, 5 ve 9 kartlarını aşağıdaki toplama işleminin sonucunun en büyük olmasını sağlayacak şekilde yerleştirin.



D. 2, 3 ve 9 kartlarını aşağıdaki çıkarma işleminin sonucunun en büyük olmasını sağlayacak şekilde yerleştirin.



E. 1, 4 ve 5 kartlarını aşağıdaki çarpma işleminin sonucunun en büyük olmasını sağlayacak şekilde yerleştirin.



(TIMMS, 2003)

A: Toplama işleminde belirli rakamları düzenleyerek en büyük sayıyı elde etme

Kod	Cevap	Madde: 8A
	Doğru Cevap	
10	91 + 5 veya 95+1	
11	91 + 5 veya 95+1’ in yazılması ancak toplama işleminin yanlış yapılması	
	Yanlış Cevap	
70	1,5 ve 9 rakamlarının diğer kombinasyonları	
79	Diğer tür yanlışlar	
	Cevaplanmamış	
99	Boş	

B: Çıkarma işleminde belirli rakamları düzenleyerek en büyük sayıyı elde etme

Kod	Cevap	Madde: 8B
	Doğru Cevap	
10	93-2	
11	93-2 'nin yazılması ancak çıkarma işleminin yanlış yapılması	
	Yanlış Cevap	
70	92-3	
71	2,3 ve 9 rakamlarının diğer kombinasyonları	
79	Diğer tür yanlışlar	
	Cevaplanmamış	
99	Boş	

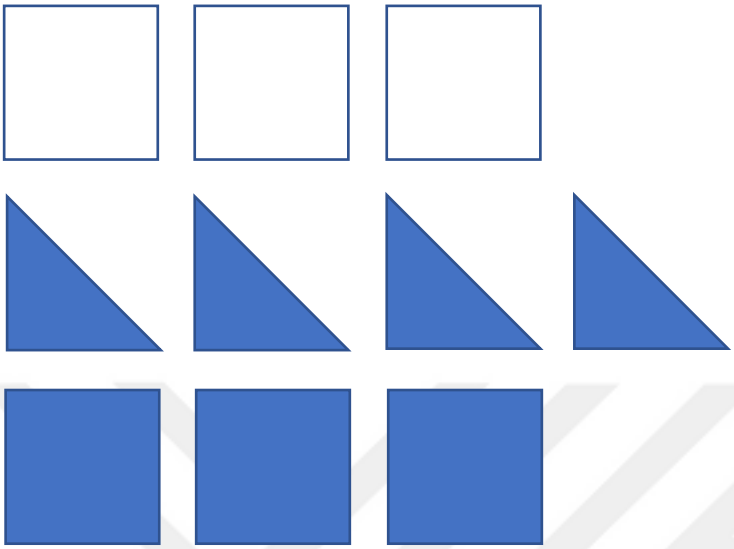
C: Çarpma işleminde belirli rakamları düzenleyerek en büyük sayıyı elde etme

Kod	Cevap	Madde: 8C
	Doğru Cevap	
10	41 x 5	
11	41 x 5’in yazılması ancak çarpma işleminin yanlış yapılması	
	Yanlış Cevap	
70	51 x 4	
71	1,4 ve 5 rakamlarının diğer kombinasyonları	
79	Diğer tür yanlışlar	
	Cevaplanmamış	
99	Boş	

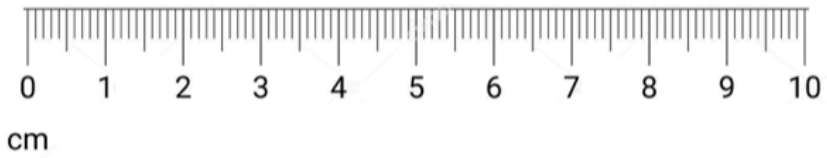
SORULARI ÇÖZERKEN KULLANILACAK MATERYALLER

Burada verilen materyaller öğrenciler tarafından kesilip ilgili soru için kullanılmak üzere hazırlanmıştır.

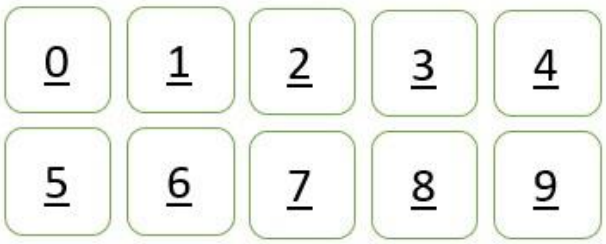
Soru 5:



Soru 7:



Soru 8:



APPENDIX E

GAME DESIGN FRAMEWORKS

Table E1. Sequences of Dot Enumeration Tasks

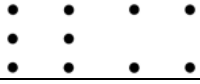
The random and canonical dot arrays adapted from Goukon's (2016) study.		
1 	9 	17 
2 	10 	18 
3 	11 	19 
4 	12 	20 
5 	13 	21 
6 	14 	22 
7 	15 	23 
8 	16 	24 

Table E2. Details of Number Sense Activities in Minecraft Video Game

Task Number	Name of the tasks	Narration	The goal of the activity	Randomized order of the dot arrays	Estimated numbers on the number line
1	Reporting Ocean Pollution	The ocean is polluted, and immediate action must be taken.	Subitizing	24, 14, 13, 8, 18, 4, 10, 23, 20, 11, 16, 1, 12, 9, 22, 2, 7, 6, 5, 15, 17, 19, 3, 21, 8, 3, 23, 5, 20, 7, 2, 14	
2	Waste Detection in the Dark	Ocean pollution reporting continues, but the dark is full of dangers.	Subitizing	11, 12, 4, 17, 16, 19, 10, 18, 21, 22, 9, 6, 13, 15, 24, 15, 18, 6, 7, 4, 24, 23, 19, 21, 11, 16, 8, 22, 17, 2, 10, 15	
3	Chemical wastes in water	Chemical wastes were reported as one of the reasons for water pollution.	Subitizing	18, 6, 7, 4, 24, 23, 19, 21, 11, 16, 8, 22, 17, 11, approximate (49), 10, approximate (73), 9, 12, 13, 14, 3, 20, 5, 17, 14, 24, 13, approximate, 23, 14, 15,	
4	Plastics Floating in the Ocean	Plastics were floating on the surface. Please report the quantity.	Subitizing	20, 6, 9, 19, 18, 12, 16, approximate (60), 5, 4, 6, 14, 7, 9, approximate (53), 12, approximate (89), interval (67), 10, 15, 19, (39), 23, 13, interval (41), 18, 22, 8, 24, 21, 20, 17, 14, 5	
5	Metal Waste	Wastes of metal sank on the deep, which decompose in decades.	Subitizing	11, 22, 6, 9, 7, 18, 20, approximate (78), 4, 1, 19, 5, 16, 21, approximate (82), 24, approximate (80), 10, 12, 8, 13, 4,7, 12, 23, 18, 14, interval (50), 11, 8, interval (90), 6, 21, 20, 17, 22	
6	Waste of masks, gloves, and bottles	Because of the epidemic, the wastes of masks and gloves are all around the ocean.	Subitizing	19, 16, 10, 13, 9, 6, 23, approximate (65), 7, 10, 11, 15, 13, 14, 12, approximate (30), 24, 8, 5, 20, 9, 16, 11, 21, 15, 8, 4, interval (52), 22, 15, interval (52), 17	
7	Global Warming Number Line	The ice is melting because of global warming. Report the melting rate to	Estimation on 0-10 Number Line		2, 3, 4, 6, 7, 8, 9, 1, 5

		raise awareness.		
8	Barren Land One	There is drought. Farmers are unhappy. Help farmers to find water by digging the correct location of the number on the hundred number line.	Estimation on 0-100 Number Line	25, 52, 42, 29, 28, 90, 33, 96, 81, 64, 72, 86, 57, 39, 17, 48, 7, 45, 21, 61, 4, 12, 17, 79
9	Solution to deforestation1	Forests are diminishing. Deforestation led to the loss of fertile land; therefore, trees cannot grow. Find the locations of the fertile soil by estimating the right location on the thousand number line.	Estimation on 0-1000 Number Line	158, 612, 504, 724, 240, 342, 56, 392, 468, 448
10	Solution to deforestation2		Estimation on 0-1000 Number Line	124, 32, 564, 820, 880, 396, 768, 904, 276, 672

APPENDIX F

PICTURES OF NUMBER SENSE GAME



Figure F1. Screenshot of the map in night



Figure F2. Screenshot of the map in day light

Trial area before beginning subitizing tasks.	**NPC interface**
	
An example of random dot arrays	**An example of canonical dot arrays**
	
Puffer fish shows up after 3 seconds from diving.	**If the player stays in the water, the fish will poison her and her life bar will start to drop.**
	
Feedbacks	**Score bar increases by then points when they correctly enumerate**
	

Figure F3. Subitizing and counting activities

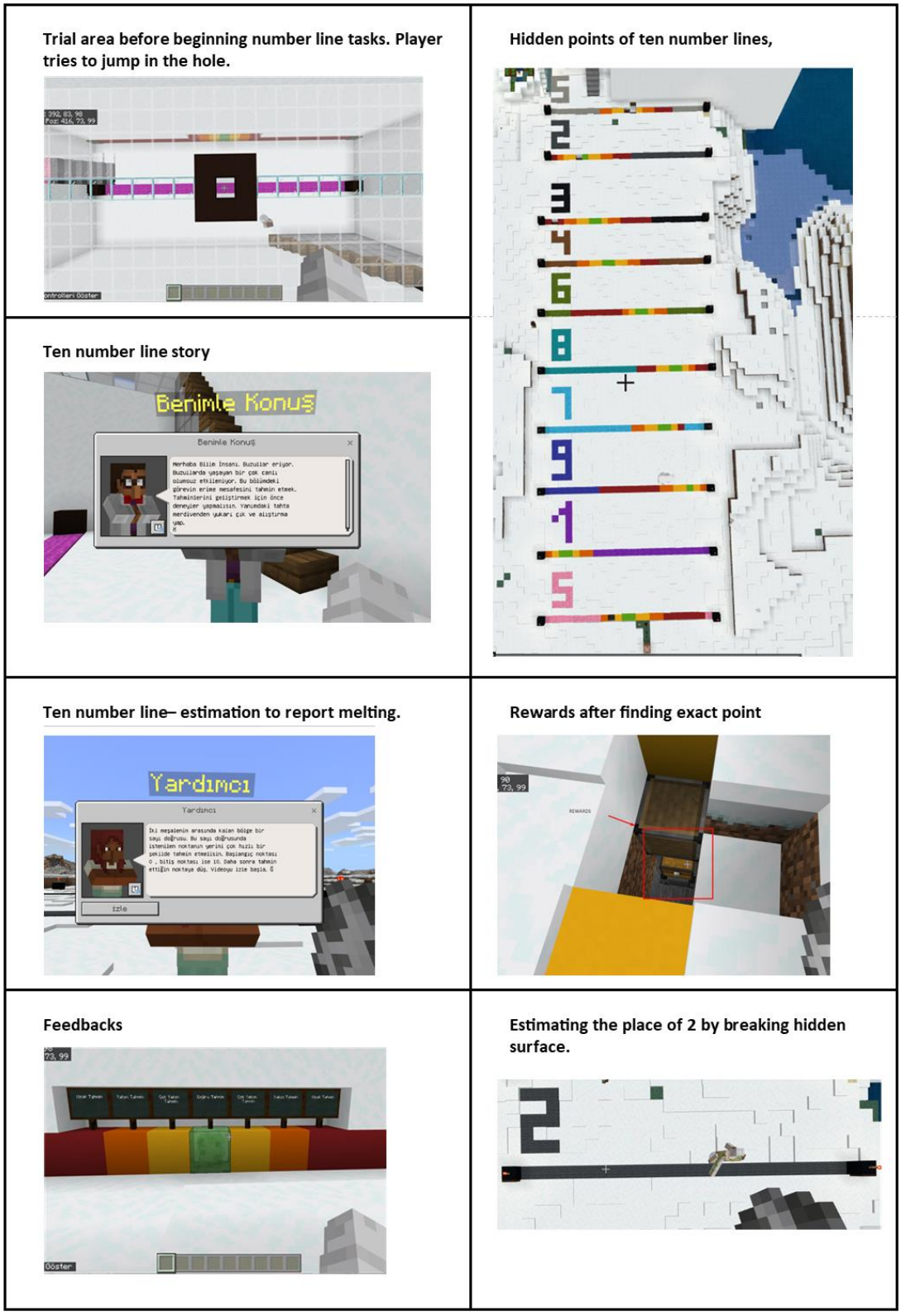


Figure F4. The ten number line tasks: melting ice

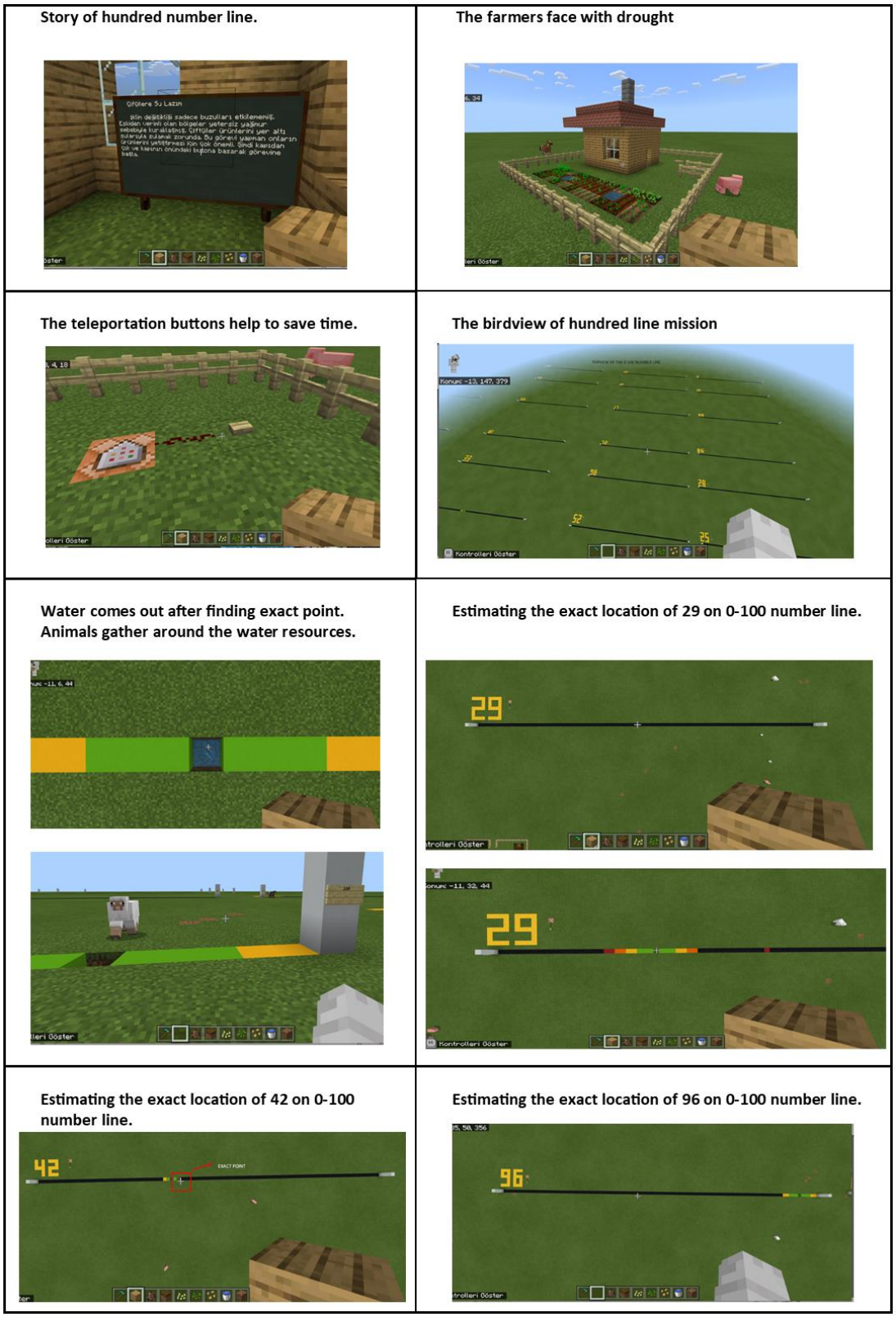


Figure F5. The hundred number line tasks: drought

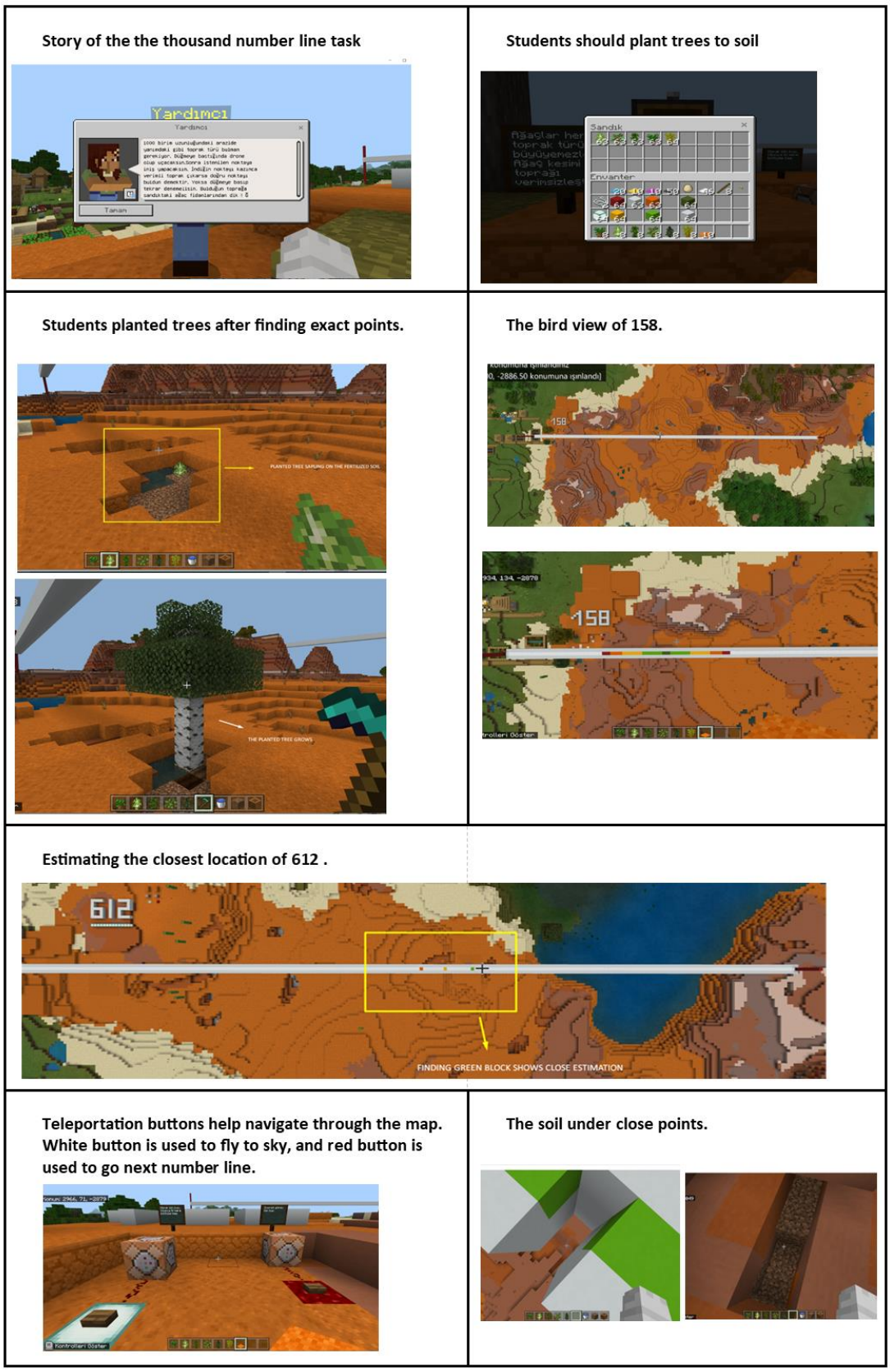


Figure F6. The thousand number line tasks: deforestation



Figure F7. Narrative elements: water pollution, global warming, drought, and deforestation



Figure F8. Narrative elements global warming, drought, and deforestation

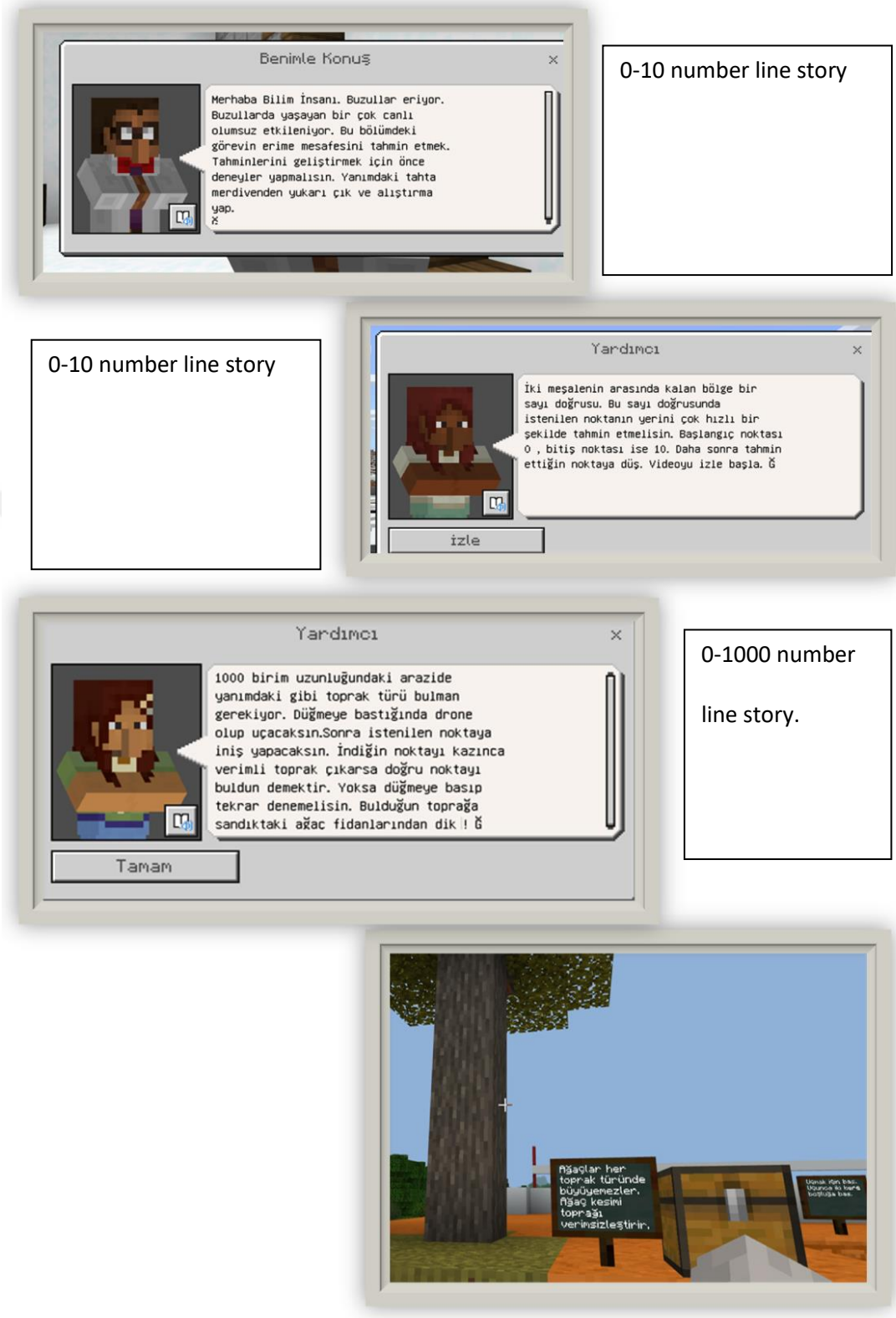


Figure F9. Narrative elements of number line tasks

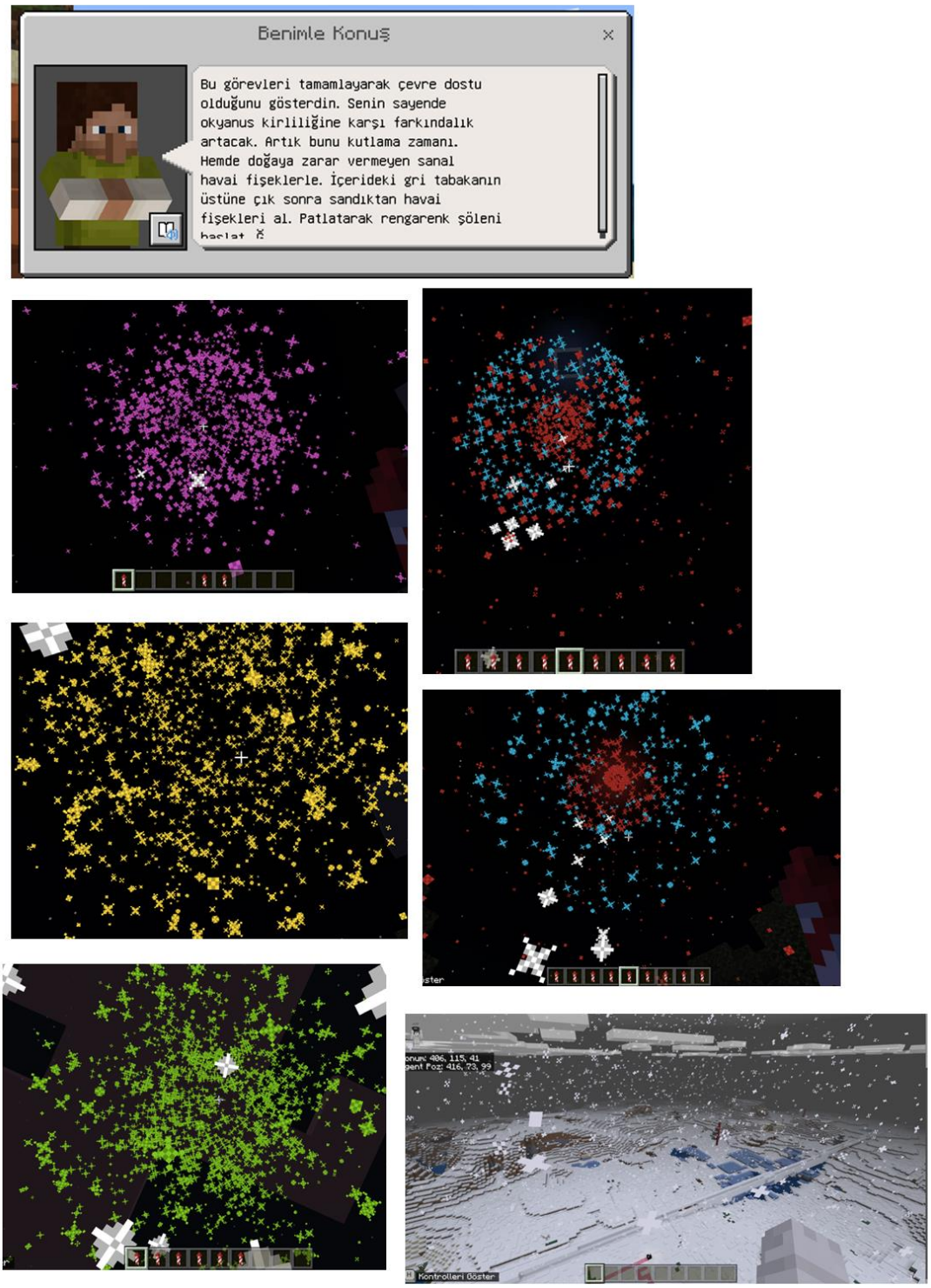


Figure F10. Aesthetics elements visual art

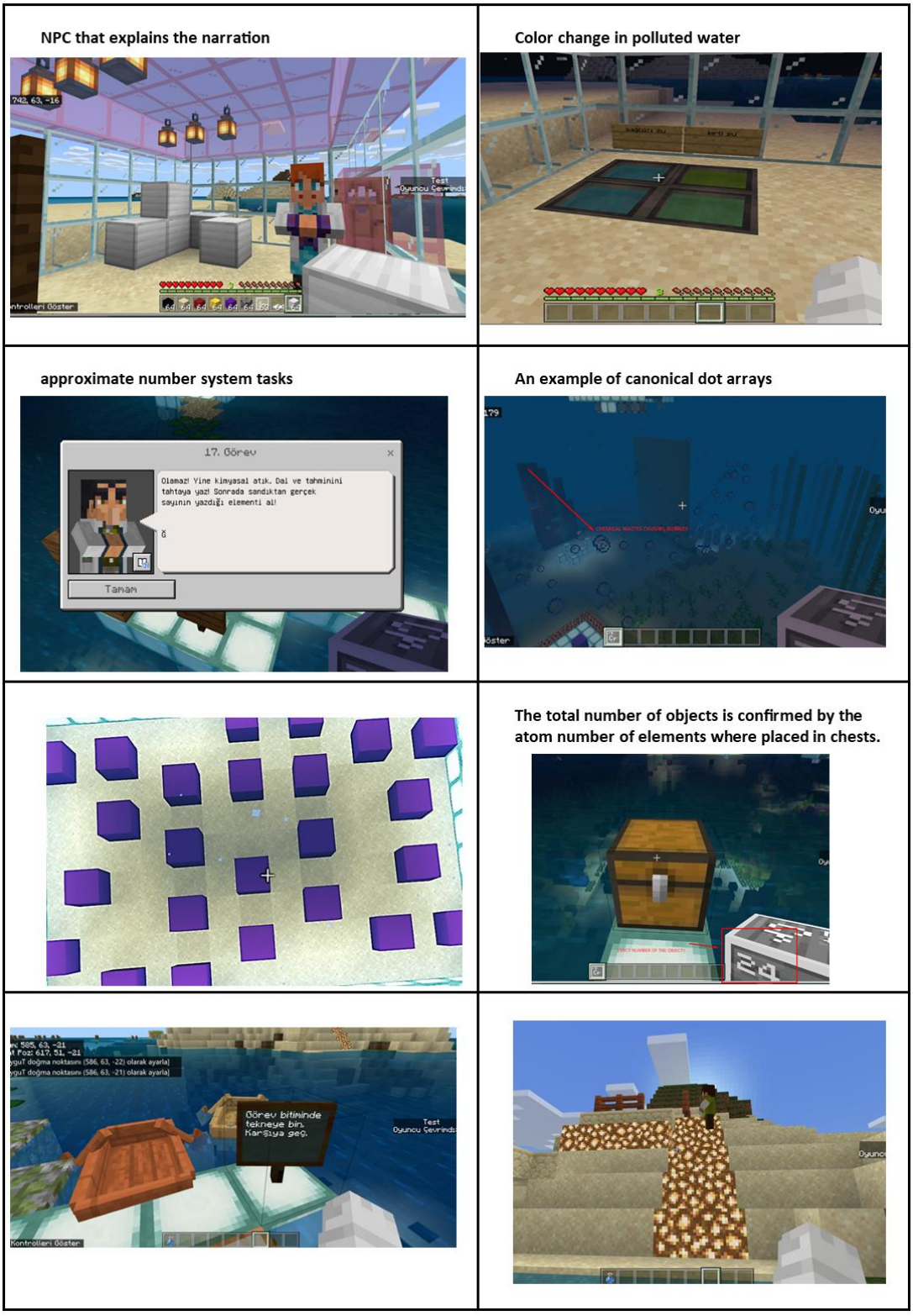
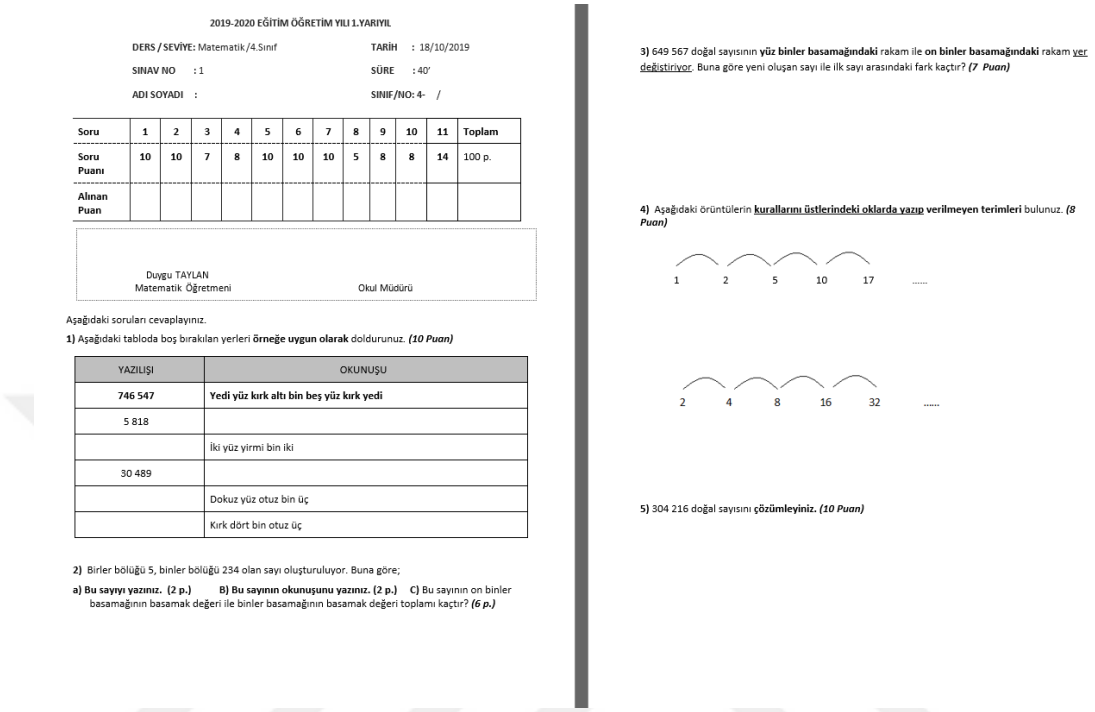


Figure F11. Aesthetics elements

APPENDIX G

MATHEMATICS EXAMS



2019-2020 EĞİTİM ÖĞRETİM YILI 1.YARIYIL

DERS / SEVİYE: Matematik /4.Sınıf **TARİH** : 18/10/2019

SINAV NO : 1 **SÜRE** : 40'

ADI SOYADI : **SINIF/NO:** 4- /

Soru	1	2	3	4	5	6	7	8	9	10	11	Toplam
Soru Puanı	10	10	7	8	10	10	10	5	8	8	14	100 p.
Alınan Puan												

Duygu TAYLAN
Matematik Öğretmeni

Okul Müdürü

Aşağıdaki soruları cevaplayınız.

1) Aşağıdaki tabloda boş bırakılan yerleri **örneğe uygun olarak** doldurunuz. ***(10 Puan)***

YAZILIŞI	OKUNUŞU
746 547	**Yedi yüz kırk altı bin beş yüz kırk yedi**
5 818	
	İki yüz yirmi bin iki
30 489	
	Dokuz yüz otuz bin üç
	Kırk dört bin otuz üç

2) Birler bölüğü 5, binler bölüğü 234 olan sayı oluşturuluyor. Buna göre;

a) Bu sayıyı yazınız. (2 p.) **B) Bu sayının okunuşunu yazınız. (2 p.)** **C)** Bu sayının on binler basamağının basamak değeri ile binler basamağının basamak değeri toplamı kaçtır? ***(6 p.)***

3) 649 567 doğal sayısının **yüz binler basamağındaki** rakam ile **on binler basamağındaki** rakam yer değiştiriyor. Buna göre yeni oluşan sayı ile ilk sayı arasındaki fark kaçtır? ***(7 Puan)***

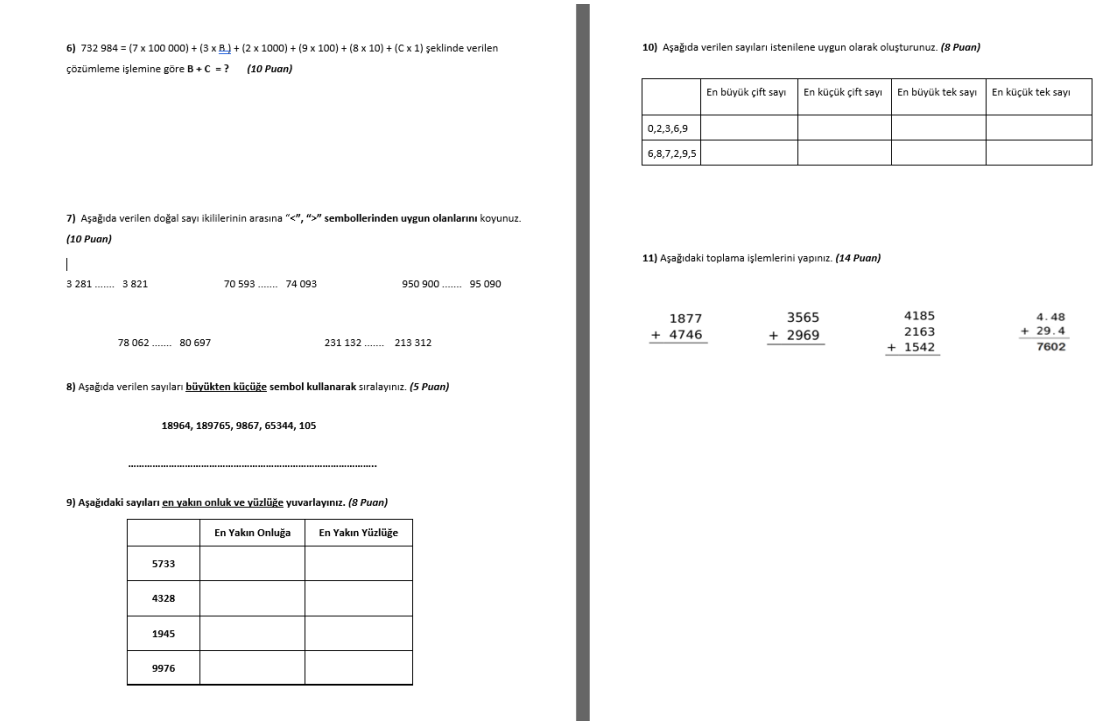
4) Aşağıdaki örüntülerin **kurallarını üstlerindeki oklarda yazıp verilmeyen terimleri** bulunuz. ***(8 Puan)***

1 2 5 10 17 .....

2 4 8 16 32 .....

5) 304 216 doğal sayısını **çözümleyiniz.** ***(10 Puan)***

Figure G1. Number knowledge questions in the first mathematics exam



6) 732 984 = (7 x 100 000) + (3 x B.) + (2 x 1000) + (9 x 100) + (8 x 10) + (C x 1) şeklinde verilen çözümleme işlemine göre **B + C = ?** ***(10 Puan)***

7) Aşağıda verilen doğal sayı ikililerinin arasına ***"<", ">"* sembollerinden uygun olanlarını** koyunuz. ***(10 Puan)***

3 281 ..... 3 821 70 593 ..... 74 093 950 900 ..... 95 090

78 062 ..... 80 697 231 132 ..... 213 312

8) Aşağıda verilen sayıları **büyükten küçüğe sembol kullanarak** sıralayınız. ***(5 Puan)***

18964, 189765, 9867, 65344, 105

.....

9) Aşağıdaki sayıları en yakın onluk ve yüzlüğe yuvarlayınız. ***(8 Puan)***

	En Yakın Onluğa	En Yakın Yüzlüğe
5733		
4328		
1945		
9976		

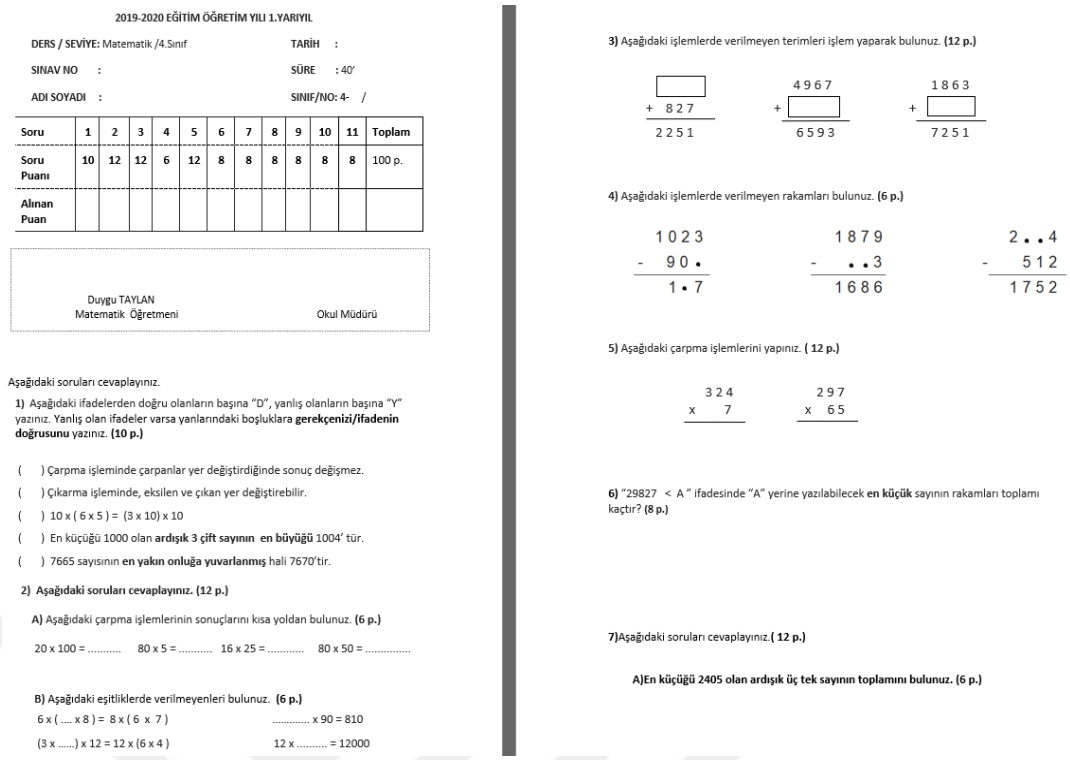
10) Aşağıda verilen sayıları istenilene uygun olarak oluşturunuz. ***(8 Puan)***

	En büyük çift sayı	En küçük çift sayı	En büyük tek sayı	En küçük tek sayı
0,2,3,6,9				
6,8,7,2,9,5				

11) Aşağıdaki toplama işlemlerini yapınız. ***(14 Puan)***

1877 + 4746 3565 + 2969 4185 + 2163 + 1542 4.48 + 29.4 = 7602

Figure G2. Arithmetic questions in the first mathematics exam



2019-2020 EĞİTİM ÖĞRETİM YILI 1.YARIYIL

DERS / SEVİYE: Matematik /4.Sınıf **TARİH :**

SINAV NO : **SÜRE :** 40'

ADI SOYADI : **SINIF/NO:** 4- /

Soru	1	2	3	4	5	6	7	8	9	10	11	Toplam
Soru Puanı	10	12	12	6	12	8	8	8	8	8	8	100 p.
Alınan Puan												

Duygu TAYLAN
Matematik Öğretmeni

Okul Müdürü

Aşağıdaki soruları cevaplayınız.

1) Aşağıdaki ifadelerden doğru olanların başına "D", yanlış olanların başına "Y" yazınız. Yanlış olan ifadeler varsa yanlarındaki boşluklara **gerekçenizi/ifadenin doğrusunu** yazınız. **(10 p.)**

( ) Çarpma işleminde çarpanlar yer değiştirdiğinde sonuç değişmez.
( ) Çıkarma işleminde, eksilen ve çıkan yer değiştirebilir.
( ) 10 x (6 x 5) = (3 x 10) x 10
( ) En küçüğü 1000 olan **ardışık 3 çift sayının en büyüğü** 1004' tür.
( ) 7665 sayısının **en yakın onluğa yuvarlanmış** hali 7670'tir.

2) Aşağıdaki soruları cevaplayınız. (12 p.)

A) Aşağıdaki çarpma işlemlerinin sonuçlarını kısa yoldan bulunuz. **(6 p.)**

20 x 100 = ... 80 x 5 = ... 16 x 25 = ... 80 x 50 = ...

B) Aşağıdaki eşitliklerde verilmeyenleri bulunuz. **(6 p.)**

6 x (.... x 8) = 8 x (6 x 7) ..... x 90 = 810

(3 x .....) x 12 = 12 x (6 x 4) 12 x ..... = 12000

3) Aşağıdaki işlemlerde verilmeyen terimleri işlem yaparak bulunuz. **(12 p.)**

□ + 827 = 2251 4967 + □ = 6593 1863 + □ = 7251

4) Aşağıdaki işlemlerde verilmeyen rakamları bulunuz. **(6 p.)**

1023 - 90• = 1•7 1879 - ••3 = 1686 2••4 - 512 = 1752

5) Aşağıdaki çarpma işlemlerini yapınız. **(12 p.)**

324 x 7 297 x 65

6) "29827 < A " ifadesinde "A" yerine yazılabilecek **en küçük** sayının rakamları toplamı kaçtır? **(8 p.)**

7)Aşağıdaki soruları cevaplayınız.**(12 p.)**

A)En küçüğü 2405 olan ardışık üç tek sayının toplamını bulunuz. (6 p.)

Figure G3. Arithmetic questions in the second mathematics exam



B)Büyüğü 6786 olan ardışık iki çift sayının toplamını bulunuz. (6 p.)

8) Bir kasabada 1460 kadın, kadınlardan 680 daha az erkek ve erkeklerin iki katı kadarda çocuk vardır. İlçemizdeki çocuk sayısı kaçtır?**(8 p.)**

9) 1850 lirası olan Ayşe Hanım, 880 lira olan bir müzik çalar ve 1340 lira olan bir masa almak istiyor. Ayşe Hanım'ın kaç liraya daha ihtiyacı vardır? **(8 p.)**

10) Bir terzi 156 liraya aldığı kumaştan elbise dikiyor. Bu elbiseyi 983 liraya satıyor. Terzi bu elbiseden **18 tane** satarsa kaç lira kar eder? **(8 p.)**

11) 8999 liralık bilgisayar için **her ay 345 lira** ödeyen kişinin 6. taksitini ödediğinde ne kadar borcu kalır? **(8 p.)**

Figure G4. Word problems in the second mathematics exam

APPENDIX H

INTERVIEW PROTOCOL AND CODE TABLE

The interview begins by chatting with the student. They are asked about their plans for the holiday and the conversation is started by following the steps below. Eight questions are asked to the student. Questions with sub-questions are asked in order of priority if the answer is not included in the student's answer.

The purpose of this interview is to understand your opinions about Minecraft Number Sense game and game experiences when playing these games.

Question 1: What do you think about the game?

- Have you played Minecraft before?
    - Have you played Minecraft Edu?
- How did you feel playing the games?

In order to understand the game flow, the following questions are asked to the participant.

Question 2: Let's try to remember all the episodes in the game. Can you tell me what you remember?

- If you have a favorite episode, can you tell me about the features you like about this episode?
- Could you tell me what you did in different tasks of the game?
    - Did you understand what to do while doing these tasks?
- What do you think about narration of these episodes you talked about?
    - How did you feel when playing episodes with narration?
- Is there anything that you prefer to change in the tasks?

Question 3: The tasks required two basic movements which are diving and flying. What do you think about diving and flying? How did you feel?

- Were you able to control your movements such as swimming, jumping, running, and flying when playing the game?

Question 4: You had 25 minutes to complete each section. Was the time given to you enough to complete the chapters?

- Was the time sufficient?
- How was the number of tasks? Were The tasks more or less?
- How did time flow while playing games?
- Was it easy to pay attention to the game?
- Did you forget the unhappy things while playing the game?

The following questions are asked to understand number sense game strategies.

The student's work is examined in advance. Screen recordings are opened to ask questions, and the following questions are asked.

Question 5: How do you decide the number of these objects?

Question 6: 0-10 number line tasks are opened.

How did you decide the place of …. ?

- You spent a lot of time here. Why do you think it took you so long to find the closest point?
- You found the green zone very quickly here. Why do you think you were able to find the nearest point quickly?

Question 7: Number line tasks of 0-100 are opened.

How did you decide the place of …. ?

- You spent a lot of time here. Why do you think it took you so long to find the closest point?
- You found the green zone very quickly here. Why do you think you were able to find the nearest point quickly?

Question 8: Number line tasks of 0-1000 are opened.

How did you decide the place of …. ?

- You spent a lot of time here. Why do you think it took you so long to find the closest point?
- You found the green zone very quickly here. Why do you think you were able to find the nearest point quickly?

Table G1. Qualitative Analysis Code Table

Apriori categories	Main themes and Sub-themes	Sample of coded text
1. Game flow elements		
• Control over actions		I: Were you able to control the swimming, running, and flying movements in the game? Rachel: I: Oh no. Since I played Minecraft on the phone before, I had no difficulty playing it. When we played with the computer at school, I had some difficulty, but as I played, I got used to it. Emily: I had a little difficulty at first, because I had not experienced Minecraft before by flying and diving… That is why, I had a hard time with it at first, but then I got used to it.
• Clear goals		I: While doing these tasks, did you know what to do at the beginning of each map? Luna: Almost all my answers were incorrect while playing the first episode… because I was playing without knowing what to do... Then I called Rachel and she told me what to do… After Rachel explained, I did all the tasks correctly. R: Do you think it was important for Minecraft number sense to have goals? Darcey: I think it's good to have a purpose because you don't understand anything about the game when you wander around like this, but when you have a goal, you try to realize it.
• Feedbacks		I: How was it for you to get +10 points as you answer the tasks? Rachel: It was satisfactory.
• Loss of sense of time		I: How did time flow while playing these games? Luna: I thought that time passes very slowly in computer games, but I realized that it is not so. The time was running out so fast. Darcey: Time passed so fast.
• Concentration		I: Was it easy to concentrate when playing the game? Did you think about anything else while doing the tasks,did you think of different things? Rachel: I was very concentrated, and I gave my attention easily... I played the game a little fast, but I completed the tasks carefully.

	Game experience/ design	
	• Supports by the game for strategy use	I: Can you tell me a little about what the last games I sent were about? What did you learn from these games? And, what do you think about these games? Zoey : I learned that it is necessary to find the exact middle on the number line.
	• Time constraint	R: You had 25 minutes to play each map. Do you think 25 minutes was enough? Luna: I think 25 minutes was enough. I completed the initial tasks in a maximum of 25 minutes because I didn't know what I was doing. My playing time towards final maps decreased to 10 minutes.
	Learning with Minecraft	I: Can you explain the good aspects of the game? Rachel: Thanks to the game, my interest in learning increased. I: What did you become more interested in learning about? Rachel: Estimating the numbers. For example, I usually can't estimate well. But this game both improved my estimation skills and increased my interest in estimation tasks.
	Minecraft number sense game	
	Experience fun	I: So Rachel, do you think the tasks were fun? R: The games were very funny. I: Well, can you explain the aspect that you find most entertaining, for example, what was the funniest feature? Rachel: What was fun was that you turned a game into a lesson, and these tasks were very colorful. I liked it.
	Narration	I: Do you think Minecraft guessing missions was a good game? What aspects did you find the best? Darcey: First of all, I think we are learning to play Minecraft. After that, I realized that there is a lot of environmental pollution and…we should live in a way that pollutes nature less, not this way. Apart from that, I realized that mathematics lessons are a very fun and very good lesson.
Number sense strategies		

	1. Subitizing and counting strategies	Random dot counting grouping strategy	I: How do you decide it's 10? Luna: I counted 3 by 3. When I counted 9 of them, another one appeared. I realized it was 10.
		Canonic dot counting grouping strategy	I: How did you quickly decide that this was 6? Adrian: It was easy. I: How did you see this? Can you tell me how did you see it when you first saw it? Adrian: There were 6 cubes. (canonical) I: When you look at this shape, do you immediately see 6? Don't you count? Adrian: Yes, I immediately understand that there are 6 of them because I see sequences like this in real life.
1.	Number line estimation strategies	Ten- hundred-thousand number line estimation strategies • Beginning point • Endpoint • Midpoint	I: How do you find the 3 here? Luna: There. I: How did you decide that it was there? Luna: Because 1, 2, 3 fit here, 4 here, and 5 here. Zoey: If it's between 0 and 10 and asked for 6, I'll go back 4 and find it. I: How do you know you have to go back 4 blocks? Zoey: I know because the sum of the two was 10. I: How do you find 52? Luna: I would go a little forward because it is the middle of 50. I: How did you find the location of 352? Rachel: I'll come to the middle where the 500 is and go a little to the left.

APPENDIX I

TURKISH VERSION OF INTERVIEW PROTOCOL

Öğrenci ile sohbet edilerek görüşmeye başlanır. Tatil için planları sorulur ve aşağıdaki adımlar takip edilerek konuşma başlatılır. **Öğrenciye numaralı soru cümleleri sorulur. Ana soru içerisindeki maddeli sorular öğrencinin cevabının içerisinde bulunmadığı durumda öncelik sırasına göre sorulur.**

Bu görüşmeyi seninle yapmamızın amacı; senin Minecraft Tahmin oyunları hakkındaki düşüncelerini ve oyun sırasındaki yaptıklarını anlamaya çalışmak.

Soru 1: Oyun hakkında ne düşünüyorsun?

- Daha önce Minecraft oynamış mıydın?
    - Minecraft Edu oynamışmıydın?
- Oyunları oynarken nasıl hissettin?

Oyunun akışını anlamak için katılımcıya aşağıdaki sorular sorulur.

Soru 2: Oyundaki tüm bölümleri hatırlamaya çalışalım. Bana neler hatırladığını anlatır mısın?

- En sevdiğin bölüm var ise bu bölümün sevdiğin özelliklerinden bahseder misin?
- Oyundaki bölümlerde neler yaptığından biraz bahseder misin?
    - Bu görevleri yaparken ne yapman gerektiğini anlayabildin mi?
- Bahsettiğin bu bölümlerin konusu ve hikayesi hakkında ne düşünüyorsun?
    - Bahsettiğin bu konular ile ilgili oyun oynamak ve görev yapmak sana nasıl hissettirdi?
- Oynadığın bölümlerden herhangi birinde burası şöyle olsaydı daha iyi olurdu dediğin bir yer var mı?

Soru 3: Bölümler içerisinde denize dalarak ve uçarak görevler yapıyordunuz. Sence denize dalarak ve uçarak görev yapmak nasıldı?

- Oyun içerisindeki yüzme, zıplama, koşma ve uçma gibi hareketlerini kontrol edebildin mi?

Soru 4: Her bir bölümü tamamlaman için 25 dakikan vardı. Bölümleri tamamlaman için verilen zaman nasıldı?

- Zaman yeterli miydi?
- Oyundaki bölümlerin sayısı nasıldı?
- Oyun oynarken zaman nasıl akıyordu?
- Oyuna dikkatini vermek kolay oldu mu?
- Oyun oynarken mutsuz edici şeyleri unuttun mu?

Sayı hissi stratejilerini anlamak için aşağıdaki sorular sorulur.

Öğrencinin yaptığı çalışmalar önceden incelenerek soru sorulacak yerleri açılır ve aşağıdaki sorular sorulur.

Soru 5: Buradaki nesnelerin sayısının …….. olduğuna nasıl karar veriyorsun?

Soru 6: 0-10'luk sayı doğrusu görevleri açılır.

…… sayısının orada olduğuna nasıl karar verdin?

- Burada çok zaman harcamışsın. Sence yakın noktayı bulman neden uzun sürdü?
- Burada yeşil bölgeyi çok çabuk bulmuşsun. Sence yakın noktayı neden çabuk bulabildin?

Soru 7: 0-100'lük sayı doğrusu görevleri açılır.

…… sayısının orada olduğuna nasıl karar verdin?

- Burada çok zaman harcamışsın. Sence yakın noktayı bulman neden uzun sürdü?
- Burada yeşil bölgeyi çok çabuk bulmuşsun. Sence yakın noktayı neden çabuk bulabildin?

Soru 8: 0-1000'lik sayı doğrusu görevleri açılır.

…… sayısının orada olduğuna nasıl karar verdin?

- Burada çok zaman harcamışsın. Sence yakın noktayı bulman neden uzun sürdü?
- Burada yeşil bölgeyi çok çabuk bulmuşsun. Sence yakın noktayı neden çabuk bulabildin?

APPENDIX J

ETHICS COMMITTEE APPROVAL

Evrak Tarih ve Sayısı: 17.05.2021-14323

T.C.
BOĞAZİÇİ ÜNİVERSİTESİ
SOSYAL VE BEŞERİ BİLİMLER YÜKSEK LİSANS VE DOKTORA TEZLERİ ETİK İNCELEME KOMİSYONU
TOPLANTI TUTANAĞI

Toplantı Sayısı	:	2
Toplantı Tarihi	:	24.02.2020
Toplantı Saati	:	13:00
Toplantı Yeri	:	Sosyal Bilimler Enstitüsü
Bulunanlar	:	Dr. Öğr. Üyesi Yasemin Sohtorik İlkmen, Doç. Dr. Ebru Kaya, Prof. Dr. Fatma Nevra Seggie, Prof. Dr. Özlem Hesapçı Karaca, Prof. Dr. Feyza Çorapçı
Bulunmayanlar	:	

Duygu Taylan
Eğitim Teknolojileri

Sayın Araştırmacı,

"Developing fourth grade students' number sense abilities in a virtual game-based learning environment" başlıklı projeniz ile ilgili olarak yaptığınız SBB-EAK 2020/02 sayılı başvuru komisyonumuz tarafından 24 Şubat 2020 tarihli toplantıda incelenmiş ve uygun bulunmuştur.

Bu karar tüm üyelerin oybirliği ile alınmıştır. COVID-19 önlemleri kapsamında kurul üyelerinden ıslak imza alınamadığı için bu onam mektubu üye ve raportör olarak Ebru Kaya tarafından bütün üyeler adına e-imzalanmıştır.

Saygılarımızla, bilgilerinizi rica ederiz.

Prof. Dr. Ebru KAYA
ÜYE

e-imzalıdır
Prof. Dr.Ebru KAYA
Raportör

SOBETİK 2 24.02.2020

Bu belge 5070 sayılı Elektronik İmza Kanununun 5. Maddesi gereğince güvenli elektronik imza ile imzalanmıştır.

APPENDIX K

CONSENT FORM

KATILIMCI BİLGİ ve ONAM FORMU

Tez başlığı: Developing fourth grade students' number sense abilities in a virtual game-based learning environment.

Dördüncü sınıf öğrencilerinin sayı hissi beceri düzeylerinin sanal oyun tabanlı öğrenme ortamında geliştirilmesi.

Tez Yürütücüsü: Dr. Öğretim Üyesi Mutlu Şen Akbulut, Doç. Dr. Serkan Özel
Adres: Boğaziçi Üniversitesi, Eğitim Fakültesi, Bilgisayar ve Öğretim Teknolojileri Eğitimi Bölümü
Telefon: 0-212-359-6789
E-posta: mutlu.sen@boun.edu.tr

Tez konusu:

Sayı hissi kavramı matematik başarısı ile doğrudan ilgili olup sayı hissi becerilerini geliştirmenin matematik başarısına olumlu yönde etkisi vardır. Bu araştırmanın amacı dijital oyunların 4. Sınıf öğrencilerinin sayı hissi konusundaki başarılarına etkisini incelemektir. Oyun temelli öğrenmenin öğrencilerin başarısını artırdığı ve derse katılımını sağladığını gösteren araştırmalar mevcuttur. Ayrıca aksiyon içeren sanal oyunlar öğretim için kullanıldıklarında, öğrencilerin çalışan bellek (working memory)'nin bir uzantısı olan görsel uzamsal bilişi (visuospatial cognition) geliştirmede önemli etkisi olduğu deneysel çalışmalarla ortaya koyulmuştur. Bu projede eğitsel dijital oyunları kullanarak 4. Sınıf öğrencilerinin sayı hissi beceri düzeylerinin geliştirilmesi amaçlanmaktadır

Sayın Veli,

Dijital eğitsel oyun olarak kullanılan Minecraft Education Edition (Minecraft Eğitim Versiyonu) adlı video oyunu, matematik derslerinde ilgili kazanımların geliştirilmesi amacıyla bilgisayar ortamında 2 hafta süre ile 4 saat boyunca uygulanacaktır. Bunun anlamı, bu çalışma çerçevesinde elde edilen ürünler ve veriler, bilimsel bir araştırma çerçevesinde değerlendirilip analiz edilecektir. Bu araştırmanın amacı, dijital oyun ile matematik öğretiminde önemli bir kavram olan sayı hissi becerilerini geliştirmektir. Dijital oyun içerisinde yapılacak çalışmalar, öğrencilerin bulunduğu seviyenin matematik müfredatına ve kazanımlarına uygun şekilde hazırlanmıştır.

Çalışmaya veri toplama ve uygulama dahil 6 matematik ders saati ayrılacaktır. Veri toplamada ön test aşaması bir ders saati, son test aşaması bir ders saati sürecektir. Ön test ve son testte kullanılacak ölçüm araçları "Temel Sayı İşlemleme Testi", "Stroop Görevi", "Corsi- Geri Corsi Blok Tıklama Görevi" ve "Go-No-Go Görevi"dir. Bu ölçüm araçları sırasıyla şipşak sayılama yetisi, sayı doğrusu tahmin becerisi ve görsel uzamsal kısa süreli çalışma belleğini ölçmeye yöneliktir. Ölçekler bilgisayar dersliğinde bilgisayarlar ile uygulanacaktır. Ön test bitiminde uygulama iki hafta boyunca toplam 4 ders saati sürecektir. Uygulama Minecraft Education Edition video oyunu ile yapılacaktır. Uygulamanın ilk haftasında iki ders boyunca öğrencilere okyanusun dibini temizleme görevi verilerek yaklaşık nesne sayısı tahmin becerilerini geliştirmeleri beklenecektir. İkinci haftasında ise iki ders boyunca 0-10, 0-100, ve 0-1000 aralıklarında verilen sayı doğrusunda istenilen noktanın yerini tespit etmesi istenecektir.

Araştırmaya katılmayan öğrenciler sınıflarında sınıf öğretmenleri ile birlikte o haftanın matematik kazanımları ile ilgili çalışma yapacaktır. Katılmayan öğrencilere isterlerse video oyunun okul ödev sisteminden gönderileceği söylenecektir. Bu araştırma için ayrılan matematik ders saatleri okulun sunduğu etüt saatlerinde, katılmayan öğrencilerle birebir aynı olan ders planı uygulanıp araştırmaya katılanların ders eksiklikleri aynı hafta içerisinde giderilecektir. Etüt dersleri her hafta içi iki gün iki ders saati olmak üzere, üç hafta boyunca işlenecektir.

Uygulama içerisinde öğrencilerin yapacağı çalışmalar bu araştırma için veri teşkil edecektir. Ayrıca çalışma başında rastgele seçilen iki öğrencinin 30 dakika boyunca oyun sırasındaki davranışlarını gözlemlemek için öğrencilerin yüzü gözükmeksizin oynadıkları bilgisayarların ekranı taranarak video kaydı alınacaktır. Bu görüşmelerde oyundaki davranışları ile ilgili "buraya neden tıkladın?" "Görevleri yaparken zorlandın mı?" gibi oyun sırasındaki davranışları anlamlandırmak üzere kısa sorular sorulacak, ses kayıt cihazı ile kaydedilecektir. Veri analizi sonrası belli bir süre saklanan kayıtlar imha edilecektir.

Ön test ve son test sonucu elde edilecek veriler, sunulacak bildiri veya yayınlanacak makalelerde kullanılabilir. Ancak öğrencilerin kimlikleri hiçbir şekilde çalışmanın bulgularında geçmeyecektir.

Öğrencilerin bu araştırmaya katılmaları zorunlu değildir. İstedikleri zaman çalışmadan çekilebilir ve verilerin kullanılmamasını talep edebilirsiniz. Ancak araştırmaya katılımınız ve onayınız sayesinde, eğitsel-sanal oyunların sayı hissi kavramı üzerindeki katkıları anlaşılabilecektir. Bu çalışma ile ilgili olarak bilinen hiçbir risk veya rahatsızlık yoktur.

Bu çalışmanın amaç ve prosedürlerinden tamamen haberdar olarak öğrencilerin yapacağı çalışmaların, bilgisayar ekran kaydı ve röportaj verilerinin bu bilimsel çalışma çerçevesinde değerlendirilebilmesi için onayınızı gösteren aşağıdaki kısmı lütfen imzalayınız.

Onam: Öğrencilerin çalışmaya katılmaları durumunda; toplamda 6 matematik dersinin ilk hafta bir ders ve son hafta bir ders sürecek ön test son test çalışmaları için 4 matematik ders saatinin dijital oyun çalışmalarına ayrılacağını kabul etmiş olursunuz.

Çalışmanın veri toplama sürecine katılmanız tamamen isteğe bağlıdır. İstediğiniz zaman velisi olduğunuz öğrencinin çalışmaya katılmasından vazgeçebilirsiniz. Bu durumda öğrenciden almış olduğumuz veriler çalışmada kullanılmayacaktır. Yapmak istediğimiz araştırmanın velisi olduğunuz öğrenciye risk getirmesi beklenmemektedir. Araştırmanın öğrencilerin sayı hissi ve tahmin becerilerini geliştirmesi muhtemeldir. Bu formu imzalamadan önce, çalışmayla ilgili sorularınız varsa lütfen sorun. Daha sonra sorunuz olursa, tez yürütücüsü Mutlu Şen Akbulut'a (Ofis Telefonu: 0212 359 67 89) sorabilirsiniz. Araştırmaya katılımınızla ilgili daha fazla bilgi için Sosyal ve Beşerî Bilimler Yüksek Lisans ve Doktora Tezleri Etik İnceleme Komisyonu ile iletişime geçebilirsiniz.

Bana anlatılanları ve yukarıda yazılanları anladım. Bu formun bir örneğini aldım / almak istemiyorum (bu durumda araştırmacı bu kopyayı saklar).

Çalışmaya katılmayı kabul ediyorum.

Veli Adı Soyadı: …… Katılımcı Adı-Soyadı: ……..
Veli İmzası: ……
Tarih (gün/ay/yıl): ...../...../.....

Araştırmacı Adı-Soyadı: ……

İmzası: .....

Tarih (gün/ay/yıl): ...../...../.....

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Duygu Taylan

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