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Examining the pre-school aged children's counting skills: A teaching experiment based on subitizing games

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The present study was designed to investigate changes in the counting abilities of 6-year-old children through playing subitizing games. A constructivist teaching experiment was conducted with 63 preschool-aged children in Turkey, with a focus on five of them. The experiment consisted of 11 sessions held over two days each week, and the counting abilities of the five children were analyzed retrospectively. The results indicated that subitizing games improved the counting and subitizing skills of preschool children at various levels. These findings suggest that subitizing games should be integrated into the classroom to facilitate early number development. Further research is needed to gain a deeper understanding of how to use subitizing games to help children develop their numerical understanding and counting skills.

Keywords: Subitizing, counting, teaching experiment, pre-school aged children, games.

Introduction

The acquisition of mathematical knowledge by young children is an area of research that has been studied in depth. While some argue that children have an innate mathematical sense (Kilpatrick et al., 2001), are able to distinguish the number of objects in clusters (Geary, 1994), and can accurately predict small addition and subtraction operations (Ginsburg et al., 1998), others argue that children reach mathematical knowledge through various experiences and learnings without prior knowledge (Newcombe, 2002). Recent research studies have supported both of these views by revealing that interventions in children's mathematical skills positively affect their later years of mathematics skills (Anders et al., 2013; Clements & Sarama, 2016; Geary, 2011). Additionally, studies have found that children with low counting scores at the beginning struggle to catch up with the averages of their peers, even if their skills improve later (Aunio et al., 2015). Therefore, it is important to develop children's counting strategies in the early years and to examine effective interventions, such as subitizing – the ability to quickly determine how many objects there are in a small group without counting them (Butterworth, 1999).

Subitizing has been identified as a key skill to explain cognitive processes connected to early number development (Clements et al., 2019), and it is necessary to examine what children will learn about mathematics in the early years and which instructional setting provides this learning (Clements & Sarama, 2007). This led to the present study, which was designed to investigate changes in counting abilities of 6-year-old children through playing subitizing games.

Conceptual Framework

Subitizing is an important cognitive skill that enables individuals to quickly and accurately identify or name a given number without having to count. It is typically divided into two distinct categories: perceptual and conceptual subitizing. Perceptual subitizing, as described by Clements and Sarama (2009), refers to the ability to recognize a number without using any mathematical process or mental

calculation. Conceptual subitizing, on the other hand, is a more advanced skill that develops after perceptual subitizing and involves the ability to identify the units of a collection of objects (such as dominoes or dice) that are placed in a certain order. According to Silverman and Rose (1980), children develop subitizing after they have mastered basic counting and use conceptual subitizing as an efficient counting strategy.

Building on the fundamental work of Clements and Sarama (2009), MacDonald and Shumway (2016) subsequently identified six types of subitizing activities, four of them are perceptual whereas two of them are conceptual. Four different types of perceptual subitizing are listed in the table below:

Table 1: The description of four types of perceptual subitizing

| Type | Description |
|---|--|
| <i>Initial perceptual subitizing</i> | Children describe the shape of the dots. |
| <i>Perceptual subgroup subitizing</i> | Children identify a number of small subgroups, but they are unable to articulate the complete composite group. |
| <i>Perceptual ascending subitizing</i> | Children numerically describe the subgroups, and then state the entire composite group. |
| <i>Perceptual descending subitizing</i> | Children first describe the composite groups before recognizing several smaller subgroups. |

In addition to these categories, MacDonald and Wilkins (2016) defined another type of perceptual subitizing as *perceptual counting subitizing*, which refers to children who subitize a subgroup of the items and count forward or backward one. Conceptual subitizing, on the other hand, was split into two categories: “rigid conceptual subitizing” and “flexible conceptual subitizing” (MacDonald & Shumway, 2016). *Rigid conceptual subitizing* indicates a limited understanding of numbers when subitizing, and children cannot identify more than one subgroup of items. *Flexible conceptual subitizing* demonstrates flexible number understanding, and when subitizing, children are able to identify two or more ways of composing items (e.g., seeing four as “two and two”, “three and one”). The present research employed the components of subitizing outlined in the conceptual framework to analyze the progression of children in utilizing counting strategies.

Methods

This research study is a constructivist teaching experiment that aims to investigate the development of children’s counting abilities and how they change over time. In this study, a teaching experiment involves a sequence of instructional episodes, each involving 2-3 children, a teacher-researcher, a witness to the teaching episodes, and video recording of the episodes (Steffe & Ulrich, 2014). The author of this study served as both the teacher and researcher, while three teachers of the children in the kindergarten acted as witnesses in their own class.

Participants

Sixty-three 6-year-old children from three different classes of the same public kindergarten school in Turkey participated in this study. The kindergarten school included children from different socioeconomic backgrounds. The participating children were taught by teachers with a minimum of

five years of teaching experience in early childhood education. Of the children, 23 were female and 40 were male. All of them voluntarily participated in the teaching experiment.

In the study, a pre-interview was conducted with each child in which their counting skills were evaluated. At the end of this interview, focus children were determined among the children who were able to count, count on and match one-to-one, knew number symbols and knew the concepts of more or less. Among the focus group children, five of them were chosen based on their initial subitizing skills. The purpose of the selection was to examine the development of counting skills among children with different initial levels. Three of the children employed the count-on strategy at the start, while the other two were perceptual subitizers. Leon, Ryan, Petra, Elvina, and Alan were the focus of the study, and the primary aim was to conduct an in-depth examination of these children.

Procedure

The teaching experiment consisted of 11 sessions held twice a week, in which the children played a different game for no more than 15 minutes each. The games used dot arrangements of numbers between 1 and 12 to enhance the children's subitizing skills. The first four sessions focused on numbers 1 to 6, followed by six sessions concentrating on numbers 5 to 10, and finally, the last two sessions devoted to numbers 9 to 12. Clements et al. (2019) suggest that various dot arrangements, colors, and sizes can be used in activities to improve subitizing skills. In this study, only dot arrangements were utilized to represent the numbers between 1 and 12, each displayed in two different arrangements: a dice-like setup (standard) and a random arrangement (non-standard). The games used in the teaching experiments consisted of nine different counting and subitizing games developed by the researcher using various dot arrangements of numbers. The table below displays one of the games used in the experiments.

Table 2: One Example of Subitizing Intervention Game

| Name of the Game | Explanation of the Game |
|----------------------|---|
| Turning Glass | <p><i>Aim:</i> To recognize and to match different representations of numbers between 1 and 6 quickly.</p> <p><i>Materials:</i> Dominoes and number cards</p> <p><i>Procedure:</i></p> <ol style="list-style-type: none"> 1. Number symbol cards are given and asked to align up to 6 under each other. 2. Dominoes are randomly distributed to the children. 3. The first player is determined and takes a domino. 4. Says the number of dots on the domino. Matches the number with the dominoes. 5. If the dots on the domino do not match any of the numbers, they remain on the player's side. 6. Then the player whose turn it is draws a domino and announces his number as the first player. The hand continues until it reaches the first player. 7. The dominoes distributed to the players continue until the game is finished. The one who has the least number of dominoes wins the game. |

Data Analysis

Retrospective analysis (Steffe & Ulrich, 2014) was employed to comprehensively understand the counting skills of the focus group children. Each session was video recorded, and field notes were taken throughout the study. This analysis allowed for observation of what the children said and did in response to the teacher-researcher during each session (Steffe & Thompson, 2000). The analysis

was ongoing, which enabled the researcher to define the children's subitizing skills after each session. Two subitizing components, perceptual and conceptual subitizing, and their subcomponents were examined during the analysis. When analyzing a child's counting skills during a game, the teacher-researcher paid attention to the child's actions, words, and materials used to justify their thinking. For example, if the child recognizes the dot arrangement of 5 and counts over 5 while identifying 8, then this child is coded as a Partial perceptual ascending subitizer. Additionally, the researcher's analysis after the third, eighth, and eleventh sessions allowed for the creation of a model of the children's counting abilities.

Findings

The results of the teaching experiment revealed that playing subitizing games enhanced preschool children's counting and subitizing abilities at various levels. To illustrate, the table below shows the subitizing levels of the children for a range of numbers.

Table 3: Children's subitizing levels at the end of the games

| Children/ # of Games | Session 1: Games 1-3 (Numbers between 1-6) | Session 2: Games 4-8 (Numbers between 5-10) | Session 3: Games 9-11 (Numbers between 1-12) |
|----------------------------|---|--|--|
| Ryan | Counting forward by ones (4-6) | Partial perceptual subgroup subitizer between 6-10 | Perceptual ascending subitizer between 8-11 |
| Leon | Counting forward by ones (3-6) | Perceptual ascending subitizer to 6 | Rigid conceptual subitizer to 10 |
| | | Partial perceptual subgroup subitizer between 6-10 | |
| Petra | Counting forward by ones (4-6) | Partial perceptual ascending subitizer between 5-8 | Perceptual ascending subitizer on 9 and 10 |
| Alan | Partial perceptual subgroup subitizer to 6 | Flexible conceptual subitizer between 4 and 7. | Perceptual ascending subitizer between 8-10 |
| Elvina | Perceptual ascending subitizer to 6 | Flexible conceptual subitizer between 7-10 | Partial perceptual ascending subitizer between 11 and 12 |

The results presented in Table 3 demonstrate that initial levels of subitizing among children caused a differentiation in their development of counting skills. Specifically, children who initially counted numbers from 1 to 6 by ones could be classified as perceptual subgroup subitizers for numbers between 1 and 6 in subsequent games. I will explain how games contribute to the development of children as individuals. At the beginning of the study, three children – Ryan, Leon, and Petra – identified numbers by counting ones. First, the development of these children who initially rely on counting to play the games will be described.

Ryan initially recognized the standard representations of numbers between 1 and 3, but counted numbers 4 to 6 by ones. Later, he learned the standard dot arrangement of the numbers 4 and 5. During the 3rd game, the objective was for the children to select the number announced by the teacher-researcher from a set of dominoes on the floor. In one instance, as the boy opposite Ryan was attempting to count the dots, he quickly picked up the correct dominoes indicating the standard dot arrangement of five. The following dialogue took place between him and the teacher-researcher:

Teacher: How did you decide on the dominoes you chose?
 Ryan: I know that's five.

In games related to numbers 5 to 10, Ryan counted the numbers 6 to 9 by ones and quickly identified number 10 using the standard dot arrangement of 5. These games established that he quickly identified 5 by recognizing the dot arrangement of 4 and quickly recognized 7 and 8 by identifying the dot arrangement of 5. Ryan learned the standard notation of number 6 at the end of the eighth game. By the end of eight games, Ryan was classified as a partial perceptual subgroup subitizer for numbers between 6 and 10, as he identified some numbers by counting ones and others quickly using subgroups or without counting. In the last session games (numbers 9 – 12), he continued to identify 10 using the standard dot arrangement of 5 and finally began counting by twos to identify number 11. For example, in the tenth game, the objective was for the children to form the number they were given by selecting 2 out of 3 different dominoes on the floor. Ryan formed the number 11 by counting the dots by twos on the dominoes shown in the picture.

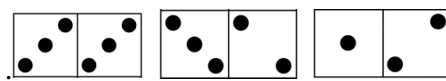


Figure 1: Dot arrangements given to Ryan to form 11

By the end of the intervention, he was classified as a perceptual ascending subitizer for the numbers between 8 and 11.

As demonstrated in Table 3, Leon began the games as a non-subitizer, relying on counting forward by ones to identify the numbers. Similar to Ryan, he counted forward from 3 to 6 in the first game, and then quickly identified 3 and 4 from the standard dot arrangement in the second game. In addition, he subitized 6 by using subgroups of 4 and 1's in this game. By the fourth game, Leon had learned the standard dot arrangement of 5 and 6, using it to identify 10 in the next game (perceptual subgroup subitizing). He also employed the standard dot arrangements of numbers 4, 5, and 6 to count numbers 6, 8, and 10, respectively, in the other game. However, as he identified the subgroups and then counted forward from these numbers by ones, his counting was classified as perceptual ascending subitizing. Leon mastered the recognition of the standard dot arrangements of all numbers from 1 to 6 by the tenth game, and then used these arrangements to count numbers from 7 to 10. Finally, when presented with non-standard number dot arrangements, Leon counted the number of dots from 9 to 12 by ones.

Petra's approach to beginning the games was similar to that of Leon and Ryan. She was able to recognize the dot configurations between 1 and 3 without counting, but for numbers between 4 and 6, she chose to count one by one. By the third game, she had acquired the ability to subitize the standard dot arrangement of 4. However, until the eighth game, she continued to use the strategy of counting by ones to identify numbers from 5 to 9. When presented with a larger number, such as 9, Petra tended to count by sets of dots. In the eighth game, she subitized 8 and 9 by recognizing the number 4, and in the following game, she learned the standard dot arrangement of 5. Finally, she used a technique of counting by twos to determine the numbers 9 and 10. It was observed that Petra was the slowest child to recognize the standard dot arrangements in the teaching experiment.

The other two children in the study, Elvina and Alan, started the games as perceptual subgroup subitizers for numbers 1 to 4. According to the research results, these children became flexible conceptual subitizers for numbers up to 10 after playing fewer games. In the following paragraphs, the development of Elvina and Alan will be described individually.

Elvina recognized the standard dot arrangements of numbers 1 to 4 in the first game. She was also aware that 5 consisted of the standard dot arrangements of 2 and 3. By the third game, Elvina had understood the standard dot arrangements of 5 and 6. During games that featured sets of 7 to 10 dots, Elvina started by counting one by one to identify the number of dots and then used smaller sets as subgroups. For example, in the fourth game, she identified 7 dots by counting forward by ones, and then in the sixth game, she employed sets of twos and counted forward by twos. The dot arrangement of 7 that Elvina encounters in the games is shown in Figure 2. In the sixth game, she counted to 7 by first pointing to the right double group, then to the right double dot in the standard arrangement of five, and then to the left double dot in the same arrangement using her hand. Finally, she said "7" while showing the middle dot.

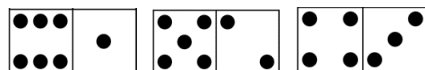


Figure 2: Dot arrangements presented to Elvina in the fourth, sixth, and seventh game respectively

Lastly, in the seventh game, she perceived the non-standard dot arrangement of 7 and counted 7 dots by using sets of 3 and 4 dots. These findings indicate that Elvina adopted diverse dot arrangements and subgroup sets to count the dots from 7 to 10, demonstrating her capacity as a flexible conceptual subitizer for numbers 1 to 10.

In addition to Elvina, Alan also began by subitizing numbers 1 to 4 and quickly identified the standard dot arrangements for 5 and 6 in the initial three games. In the fourth to eighth games, he successfully identified different non-standard dot arrangements of numbers between 5 and 10. For instance, he recognized 9 by using the dot arrangements of 5 and 4, as well as 6 and 3 in various games. Additionally, he identified 7 by employing the subgroups of 4 and 3, as well as 5 and 2. As a result of playing fewer games, he became a flexible conceptual subitizer for numbers between 5 and 10. In the last game, however, he reverted to counting one by one to identify the numbers 11 and 12.

Discussion

This study examined how playing subitizing games can potentially aid preschool-aged children in developing their counting strategies. The results of the teaching experiment revealed that the implementation of subitizing games improved the counting and subitizing abilities of preschool children at multiple levels. This is in accordance with MacDonald and Shumway's (2016) assertion that gameplay can be utilized as a form of intervention and assessment, providing teachers with a fast and efficient way to assess their children's mathematical knowledge without disrupting instruction. Consequently, this study demonstrated that subitizing games can be utilized as both an intervention and an assessment tool, allowing for the evaluation of children's counting abilities through the use of video recordings throughout the games. Despite the evidence of the benefits of playing subitizing games for preschoolers' counting skills, further research is needed to understand the exact structure and learning trajectories of the subitizing games. MacDonald (2015) emphasizes the importance of future research focusing on enhancing children's conceptual comprehension of numbers with regards to the formation of early childhood curricula.

Another finding from this study demonstrated the importance of focusing on individual numbers when conducting subitizing experiments with preschool-aged children, and the initial counting ability

of them has been identified as a factor in this alteration of acquired levels. In these experiments, it was discovered that children began by counting from 1 to 6 by ones and were classified as perceptual subgroup subitizers for the numbers from 1 to 6 in subsequent games. The children, initially exhibiting perceptual subitizing abilities, underwent a transformation, displaying a flexible conceptual subitizing of numbers up to 10 following the teaching experiment. However, the study also found that the children reverted to counting by ones or twos for eleven and twelve-dot arrangements. It is possible that this is the result of children playing fewer games that involve numbers above 10. This is in accordance with Gordon's (2004) assertion that number knowledge develops in stages, over time. Furthermore, MacDonald and Shumway (2016) recommended that when designing the games, the total number of dots should be increased by one in order to assist the child in increasing their subitizing skills. This study found that even with fewer games, children could demonstrate conceptual subitizing with certain numbers. Since the teaching experiment was conducted in collaboration with the teachers, and the teachers did not include subitizing activities in their mathematics curriculum during the experiment, it is assumed that children's development can be attributed to the related games. However, external factors outside of the school environment were not controlled, representing a limitation of the study. Further investigation is required to determine which dot arrangements children are capable of subitizing more efficiently, as well as the most advantageous learning trajectory for introducing numbers to children.

The implication of the findings of this study is that preschool-aged children can develop their counting strategies through playing subitizing games, and that these games should be focused on numbers individually. Prior research has found that early numeracy skills are essential for children's learning trajectories (Clements & Sarama, 2009; 2016).

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