

Acquisition by child of Different Numerical Symbolic and Non-Symbolic representations



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Abstract

This study examines how children acquire various numerical formats—both symbolic (Arabic numerals, number words) and non-symbolic (quantities)—during the early primary school years (first through third grade). To test the proposed hypotheses and collect data, we conducted a field study using several instruments: Raven's Progressive Matrices and four numerical tasks from the adapted Zareki battery, administered to a sample of 45 children.

The study produced several important findings, including statistically significant differences between performance on numerical mapping and numerical decoding. Differences were also found across tasks involving the various numerical formats. These differences appear to be primarily explained by grade level, suggesting a motor-cognitive mechanism influenced by developmental stage.

Keywords

Children;
Number Words;
Arabic Numerals;
Non-Symbolic Quantity;
Mapping Number;
Transcoding Number;

الكلمات المفتاحية

الطفل، الكلمات العددية،
الأرقام العربية الكتابية،
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الخرائط العددية،
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اكتساب الصيغ العددية الرمزية وغير الرمزية عند الطفل ملخص

تهدف هذه الدراسة إلى التعرف على كيفية اكتساب الأطفال الصيغ العددية المختلفة، الرمزية (الأرقام العربية الكتابية، الكلمات العددية) وغير الرمزية (الكمية)، في المرحلة الابتدائية (السنة الأولى، السنة -الثانية والسنة الثالثة ابتدائي). للتحقق من الفرضيات المصاغة وجمع البيانات، قمنا بدراسة ميدانية تم استخدام عدد من الأدوات هي: اختبار المصفوفات المتتابعة لرافن، وأربع مهام عددية من بطارية زاريكي المعدلة، وذلك على مجموعة أطفال قوامها (45 طفلاً). توصلت الدراسة إلى نتائج عديدة، نذكر منها وجود فروق دالة إحصائية بين الأداء العام للخرائط العددية وفك الترميز العددي، كما توجد فروق في مختلف المهام بين الصيغ العددية المختلفة عند الطفل في المرحلة الابتدائية. والآلية الحركية المفسرة لهذه الفروق ترجع إلى المستوى الدراسي أساساً.

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I- Introduction

The process of building mathematical competence requires multiple cognitive elements which work together to create a complex system. Children need to learn fresh concepts and practice them regularly until these operations become automatic and permanently stored in their long-term memory according to (Geary, Hoard, & Bailey, 2012). Teachers need to understand developmental phases because these stages help them make educational decisions which match students' mental progress in school learning (Nouani, 2018). The information enables specialists to detect children who need help with math learning and dyscalculia so they can create early intervention programs and personalized educational methods. Academic achievements in mathematics lead to better results in school education and career advancement.

Researchers have dedicated extensive study to understanding cognitive processes which underlie mathematical skill development in elementary school students throughout the last ten years. The study of numbers and spatial arrangements and their relationships and combinations and generalizations and abstractions defines mathematics as a subject which places numbers at the heart of mathematical understanding. Tracing the developmental trajectories of these numerical representations and the associations formed among them—whether through number mapping skills or decoding processes—is therefore a key factor in mathematical development. We concentrate on these two abilities because research shows they explain most of the differences in math skills during childhood according to (Kolkman, Kroesbergen, & Leseman, 2013).

I.1 The Onset of Quantity Encoding (Introduction to Numerical Mapping Skills)

Recent studies have confirmed that infants possess an early sensitivity to quantities and numerical changes as early as the first year of life, as the human brain is endowed with an innate mechanism for perceiving quantities (Dehaene S. , 1997, p. 47). This is evident in the ability of infants, only a few days old, to discriminate between two quantities presented within a given context (Antell & Keating, 1983). This ability is attributed to what is known as "numerical sense" at early developmental stages, which is understood as the capacity to represent and manipulate non-symbolic numerical quantities, independent of formal mathematical instruction—an ability that has also been observed in societies without systematic mathematics education (Pica, Lemer, Izard, & Dehaene, 2004).

These findings thus affirm that numerical sense constitutes a robust semantic foundation supporting the development and acquisition of later numerical skills characterized by precision and exactness. Within this framework, and drawing upon evidence from double dissociation cases in adults (neuropsychological studies), Dehaene (1992) proposed the Triple-Code Model of numerical processing, which distinguishes between two principal formats:

- Non-symbolic format: represented by quantities or sets of elements, such as dots.
- Symbolic format: including Arabic numerals (e.g., 15) and verbal number words (e.g., "fifteen").

Learning to associate these numerical formats is considered a major milestone in early mathematical development. Research indicates that children's ability to map between symbolic and non-symbolic formats is correlated with their early performance in arithmetic tasks (Brankaer, Ghesquière, & De Smedt, 2013; Short & Mclean, 2023). While adults can easily shift between different numerical formats, learning to establish these connections poses a considerable challenge for young children.

The child develops numerical mapping abilities by first learning to connect nonsymbolic number representations with verbal number words which means they understand three or four dots represent the words "three" and "four". Most children can recite number words in order from one to four by the time they reach two years old. However, such recitation is largely rote and does not necessarily indicate an understanding of the cardinal value associated with each word. Children at this stage memorize the counting sequence by treating it as a group of words. The initial routine which teaches children to match exact quantities with number words happens through counting.

When asked to collect a specific number of objects from a larger set, as in the *Give-a-Number Task* (Wynn, 1992), the child initially provides a random number of objects without regard to the requested quantity. This stage is referred to as the "pre-number-knower" stage, in which the child has not yet acquired the cardinal meaning of number words. The process of acquiring cardinal understanding proceeds through two distinct phases:

- The Subset-Knowing Stage: In this stage, children begin to learn the numerical meaning of the number words *one*, *two*, *three*, and *four* in a fixed order (Wynn, 1992; Sarnecka, Negen, & Goldman, 2018). This stage is referred to as *partial number knowledge* because the child's understanding is limited to a specific portion of the counting list, with an upper limit of four—corresponding to the range of rapid visual enumeration (*subitizing*). This capacity aligns with the number of items that can be simultaneously held in working

memory (Feigenson, Dehaene, & Spelke, 2004; Nouani, 2012). During this phase, children are classified as “one-knowers,” “two-knowers,” or “four-knowers,” depending on the highest number they can correctly provide when asked to count or match quantities.

- The Cardinal Principle-Knowing Stage (CP-knowers): At this stage, children undergo a conceptual “leap,” made possible through repeated associations between number words and small quantities (Carey S. , 2001; Carey S. , 2004). They come to understand that adding a single item corresponds to moving to the next number word in the counting list ($n+1$). This insight generalizes the *cardinal principle* to the entire counting sequence, enabling the child to grasp that the principle applies to all numbers beyond those initially acquired. Mastery of this concept typically requires more time—often several years (Cheung, Rubenson, & Barner, 2017). Children at this stage can match number words to quantities within their known counting range but still struggle with numbers outside that range (Lipton & Spelke, 2005). By around age four, many children succeed in understanding the cardinal principle, recognizing that the final number word in a count represents the total quantity of the set (Le corre & Carey, 2007; Sarnecka & Carey, 2008). In contrast, the ability to connect Arabic numerals with quantities develops later and usually coincides with the onset of formal mathematics instruction, which often begins when the child enters school.

1.2 Acquisition of Links Between Different Numerical Formats

The cognitive skill which enables people to create connections between different information types through symbolic and non-symbolic numerical data stands under the term mapping capacity (Mundy & Gilmore, 2009), or number transcoding. These two skills differ only in terms of the input and output procedures used to establish mappings between each symbol and its external representation. This capacity reflects a child’s potential or ability to link different numerical formats, whether symbolic (such as Arabic numerals and number words) or non-symbolic (such as quantities).

The process received extensive research attention during the past few years because experts understand it functions as the basis for developing mathematical knowledge (Kolkman, Kroesbergen, & Leseman, 2013; Meyer, 2015). Children need to understand number symbols during this skill development stage while experts debate two main theories about how they learn to match non-symbolic quantities with numerical symbols.

The traditional theory which people call the quantitative theory shows that children learn to connect symbolic numbers with non-symbolic quantities through their understanding of symbolic numbers and non-symbolic quantities. The traditional view holds that children develop numeral and number word skills through the combination of two basic number-processing systems which include the Object Tracking System (OTS) and the Approximate Number System (ANS) (Feigenson, Dehaene, & Spelke, 2004; Piazza, 2010).

- Object Tracking System (OTS): The system functions by representing numbers as distinct items which exist as separate entities in the set. The models which represent these items exist in long-term memory then function to match new item sets like $[****] = [A, B, M, N]$. The OTS operates with a small storage limit which allows it to hold between four and five items at once. The researchers found that children learn to count only up to four or five which matches this restriction (Carey, 2009; Carey, Shusterman, Haward, & Distefano, 2017; Feigenson, Dehaene, & Spelke, 2004; Piazza, et al., 2010).
- Approximate Number System (ANS): The ANS encodes numbers as rough item sets which humans mentally position along a numerical continuum. The number system holds infinite representation power which makes it the basic system for understanding all numerical concepts according to (Dehaene & Changeux, 1993; Nieder & Dehaene, 2009; Feigenson, Dehaene, & Spelke, 2004). The ANS plays a vital role in learning symbolic numbers according to multiple theoretical models which include triple code model (Dehaene S. , 1992) and) developmental model (Von Aster & Shalev, 2007). The four-stage model presents the ANS as the initial stage which functions as a basic requirement for children to connect quantities with spoken numbers and later written numbers. The second stage children learn number words which helps them build their counting abilities. Children learn to write Arabic numerals during the third stage which enables them to develop written calculation abilities. Children establish advanced numerical abilities during the final fourth stage which includes ordinal understanding to locate elements in sets for performing approximate and exact calculations and advanced arithmetic operations.

Conversely, the contemporary “symbolic theory” posits that children do not necessarily acquire the meaning of written Arabic numerals by linking them directly to their non-symbolic representations (i.e., the corresponding quantities). Rather, they learn their meaning through their prior knowledge of the corresponding verbal number words. In line with this perspective, Bialystok (1992) proposed a three-stage developmental model of symbolic numerical knowledge, comprising:

- The Conceptual Stage: At this stage children learn counting sequences which helps them develop a complete understanding of the entire counting sequence. The child develops number identification skills through this complete number understanding which enables them to separate number words from letters and other words.
- The Formal Stage: Here, the child uses analogical reasoning to learn the relationship between verbal number words and written Arabic numerals, in a manner similar to how a child learns that the sound “meow-meow” corresponds to the word “cat.”
- The Symbolic Stage: In this final stage, spoken number words and written Arabic numerals are integrated into a unified system. It is only at this point that the child becomes capable of linking the symbolic representation of numbers with their corresponding non-symbolic quantities.

In this context, several studies have examined the differing explanations proposed by the traditional and contemporary perspectives regarding how children connect various numerical formats. Among these is the study by (Benoit, Lehalle, Molina, Tijus, & Jouen, 2013), which assessed numerical mapping skills in children aged three, four, and five by administering six tasks requiring them to link numerical formats in multiple directions. The study concluded that the connection between number words and quantities was the strongest, followed by the link between quantities and Arabic numerals, whereas the direct mapping between number words and numerals was acquired later.

Hurst et al. (2017) conducted a more in-depth study than that of Benoit et al. (2013), testing 24 three-year-olds and 24 four-year-olds. The research showed that children struggled to connect written numbers with non-symbolic amounts but they showed better results when matching number words to Arabic numerals and non-symbolic quantities to number words. The research indicates that children apply their understanding of number words to connect symbolic numbers with their actual amounts. Number words and numerals exist in a direct relationship which does not need to trace back to their numerical values.

Jiménez Lira and his team discovered similar outcomes when they studied children between two and four years old who showed delayed development in connecting numbers to non-symbolic quantities. The first step of this process requires children to match non-symbolic amounts with number words before they can match number words to numerals.

The research from Bialystok (1992) shows that children first experience number words as spoken sequences before they learn to connect these words with numerals and finally understand how numerals represent actual amounts. The second mapping requires children to have mental numerical concepts which they can develop through their knowledge that every number word matches a distinct numeral and represents a specific quantity (Sella, Berteletti, Lucangeli, & Zorzi, 2017). The research by (Knudsen, Fischer, Henning, & Aschersleben, 2015) showed that children learn the cardinal meanings of number words by age five before they can associate numerals with quantities and number word to numeral learning occurs at the same time as numeral to quantity learning.

Lipton and Spelke investigated five-year-old children's numerical mapping abilities during their 2005 research study. The researchers discovered that children at this stage of development struggle to connect different numerical formats and this ability depends on their understanding of number symbols. The research by Kolkman and his team from 2013 analyzed six-year-old children to better understand how numerical formats develop and how children learn to relate different numerical representations. The researchers discovered that symbolic and non-symbolic formats together with numerical mappings start to merge during elementary school education after they first emerged as separate entities.

The results of several studies (Benoit, Lehalle, Molina, Tijus, & Jouen, 2013; Hurst, Anderson, & Cordes, 2017; Jiménez Lira, Carver, Douglas, & LeFevre, 2017; Lipton & Spelke, 2005; Kolkman, Kroesbergen, & Leseman, 2013) have collectively shed light on the early development of numerical formats and their various interconnections. Notably, most of these studies have focused on symbolic formats even prior to their full acquisition. Most children learn the symbolic representation of numbers in primary school, beginning with numbers up to six (Benoit, Lehalle, Molina, Tijus, & Jouen, 2013). This range corresponds closely to the capacity for subitizing, which is mediated by the Object Tracking System (OTS). It is well established that number processing becomes more complex as numerical magnitude increases; two-digit numbers, for instance, serve as an entry point into multidigit number understanding. This level of processing falls within the domain of the Approximate Number System (ANS).

I.3 Study Objective

This study seeks to explore the development of fundamental numerical skills among children in the early years of primary school. Its objectives are as follows:

- To examine the stages of acquisition of different numerical representations among first-, second-, and third-grade pupils, by identifying differences in overall performance on numerical tasks (specifically, number mapping and number transcoding).
- To determine the direction of these differences in performance for each numerical task, according to the processing pathway of the numerical formats—symbolic/symbolic or symbolic/non-symbolic.
- To analyze the nature of the developmental trajectories of various numerical formats (number words, written numerals, and non-symbolic quantities), and to investigate the relationships among these formats as a function of processing direction and school grade. This is based on the body of literature suggesting that the acquisition of numerical skills does not necessarily follow a strictly linear progression.

II- Field Procedures

The study employed three main field procedures, conducted sequentially:

- First Procedure: Designed to control study variables and define the research sample by administering Raven's Progressive Matrices to assess general intelligence.
- Second Procedure (Empirical): Implementation of the primary research instruments, particularly the number mapping test.
- Third Procedure (Statistical): Statistical analysis of the data collected in the preceding stages.

II.1 First Procedural Approach: Raven's Progressive Matrices Test

The primary purpose of employing this test was differential diagnosis, specifically to identify and select participants for the study sample. The version standardized for the Palestinian context by Ibrahim Mustafa (2012) was used. This test is considered one of the most well-known measures of culture-fair intelligence, as it does not rely on verbal components for the assessment of intellectual ability. Its author is John C. Raven (2000). The test may be administered either individually or in groups.

Data collection included 45 primary school children with average intelligence and typical academic performance, categorized as follows: 15 children from the first grade (ages 6–7), 15 children from the second grade (ages 7.4–8), and 15 children from the third grade (ages 8.4–9). The participants were selected from several primary schools in the province of Boumerdes.

The test was administered individually to the study group, as both cognitive and motor performance are influenced by whether the testing context is individual or group-based. According to Sweif (1959), cognitive performance tends to be superior in individual settings compared to group settings.

Direct observation revealed that most children demonstrated good readiness in handling the test's visual and logical tasks, particularly in relation to matrices in sets A and B. However, gradual difficulties were noted with matrices in set B. Additionally, it was observed that some children engaged in thinking aloud while solving the test, allowing researchers to trace their procedural steps.

The final test results indicated that mean performance improved with higher grade levels, with percentile ranks ranging between 30 and 90, varying according to the child's educational level. These scores correspond to an IQ range of approximately 90–100.

II.2 Second Procedural Approach

In this approach, we assessed the different aspects of numerical format associations through a set of tasks selected from the modified Zareki battery (Von Aster & Dellatolas, 2006). The test items were divided into two tasks based on the direction of numerical processing across the three symbolic representations of numbers—number words (e.g., *five*), written numerals (e.g., *15*), and nonsymbolic numerical quantities (e.g., *****). The items are presented as follows:

II.2.1 Symbolic Format-to-Nonsymbolic Format

This category comprises *numerical mapping tasks*. One of the selected tests was taken from the modified Zareki battery (Zareki-R), specifically the “Number Position on a Vertical Scale” task. Minor adjustments were made to the ordering of the test items to better align with the study objectives. The task ultimately included two versions:

- Oral Number Presentation Version: This version evaluates numerical skills in mapping *number words* → *nonsymbolic quantity*. The child is asked to estimate the position of a set of numbers, read aloud by the examiner, on a vertical scale ranging from 0 to 100. Six vertical lines are presented—three patterned and three unpatterned—and the child uses a pencil to indicate the estimated position of each number. This task measures the processing direction between nonsymbolic representation and number words.
- Written Numeral Presentation Version: This version evaluates numerical skills in mapping *written Arabic numerals* → *nonsymbolic quantity*. The child is shown a written numeral and is asked to indicate its position on the response sheet along a vertical scale from 0 to 100. As in the oral version, six vertical lines are presented (three patterned and three unpatterned), and the child is instructed to mark the line that best corresponds to the given numeral.

II.2.2 Symbolic-to-Symbolic Format

This category, commonly referred to as *number transcoding tasks*, falls within the set of assessments included in the modified Zareki battery (Zareki-R). Two key tests are used:

- Number Dictation Test: This test evaluates numerical skills involving the conversion of number words into written Arabic numerals. The examiner dictates a set of numbers, and the child is asked to write them down manually based on what they have heard.
- Number Reading Test: In contrast to the previous task, this test assesses numerical skills involving the conversion of written Arabic numerals into number words. The child is asked to read a series of numbers aloud.

The tests were administered individually, with a duration of approximately 15 to 20 minutes. The assessments administered to the study group were diversified, including both tasks that required linking spoken and written numerical symbols (number transcoding tasks) and tasks that required mentally representing quantity on a mental number line (numerical mapping tasks). The strategies adopted by the children varied depending on the nature of the task and their grade level.

Older children demonstrated enthusiasm, confidence, and greater speed in responding. In contrast, first-grade children made numerous errors, both lexical and syntactic, particularly with numbers containing three or more digits. Similar patterns were observed with numbers containing zeros (e.g., 1900, 1200, 503). Additional difficulties were noted in reading numbers either as isolated digits or literally (for instance, reading 305 as “three zero five” rather than “three hundred and five”). Accuracy rates in this group ranged between 20% and 35%.

Among second-grade children, performance showed improvement, with success rates exceeding 45%, although certain difficulties persisted—especially with tasks involving written numeral production (number dictation). By the third grade, performance had stabilized across the different tasks. Children demonstrated an increasingly sophisticated ability to manipulate numbers in various formats, with error rates declining and success rates surpassing 75%. These findings suggest a robust cognitive mastery of numerical symbols and the ability to perform different symbolic transformations, providing valuable insight into the gradual developmental trajectory of children’s understanding of numerical magnitude.

II.3 Statistical Analysis

Following the administration of the research instruments to the children, a series of statistical computations were carried out to test the formulated hypotheses and achieve the objectives of the study:

- First Hypothesis: This hypothesis posits the existence of statistically significant differences among primary school children in their overall performance on number mapping tasks and number transcoding tasks, attributable to the grade-level variable. To examine this hypothesis, arithmetic means and standard deviations were first calculated. Table (1) presents these descriptive results:

Table (01): Arithmetic Means and Standard Deviations of Overall Performance in Number Mapping Tasks and Number Transcoding Tasks

Study Group	Study Tasks	Mean	Standard Deviation
First Grade (n = 15)	Mapping number words to non-symbolic quantities	6.266	1.032
	Decoding numerals to number words	10.2	1.897
Second Grade (n = 15)	Mapping number words to non-symbolic quantities	8.33	1.988
	Decoding numerals to number words	13.86	3.92
Third Grade (n = 15)	Mapping number words to non-symbolic quantities	12.46	1.64
	Decoding numerals to number words	28.33	2.55

Table (1) presents the variations in children's performance across the three grade levels for both tasks. It is evident that the mean performance of children increases significantly from the first grade to the third grade. This finding indicates a continuous improvement in both numerical mapping tasks (mean scores = 6.266, 8.33, and 12.46, respectively) and numerical decoding tasks (mean scores = 10.2, 13.86, and 28.33, respectively).

A closer examination of the table reveals apparent differences in the mean scores of participants' performance in numerical tasks according to grade level (first, second, and third grade). To verify the statistical significance of these observed differences, a one-way analysis of variance (ANOVA) was conducted, as presented in Table (2).

Table (2): One-way ANOVA of differences in overall performance on numerical mapping tasks and numerical decoding tasks among children in the first, second, and third grades of primary school

	Source of Variation	Sum of Squares	DF	Mean Squares	F Value	Sig	(α)
Overall Performance in Number Mapping	Between Groups	395.078	2	197.539	75.083	0	0.01
	Within Groups	110.5	42	2.631			
	Total	505.578	44				
Overall Performance in Numeral Decoding	Between Groups	3,001.64	2	1,500.82	184.96	0	0.01
	Within Groups	340.8	42	8.114			
	Grand Total	3,342.44	44				

Table 2 presents the results of a one-way analysis of variance (ANOVA) used to examine the overall performance on numerical mapping tasks and numerical decoding tasks among primary school children (first, second, and third grades).

The numerical mapping task results showed that students from three different grade levels demonstrated statistically significant performance differences ($F = 75.083$, $p = 0.000$). The researchers used Scheffé's test for post-hoc analysis to discover the source of these differences. The results demonstrated that second-grade students showed major differences from first-grade students by 2.066 and third-grade students showed major differences from first-grade students by 6.2 and third-grade students showed major differences from second-grade students by 4.13.

The statistical analysis of numerical decoding task performance showed that students from three different grade levels demonstrated statistically significant differences in their average scores ($F = 184.960$, $p = 0.000$). The post-hoc Scheffé analysis showed multiple significant differences between groups. The first and third grade students showed the most significant difference when compared to each other with a mean difference of 18.13 and the second and third grade students showed a less significant difference with a mean difference of 14.46.

The second hypothesis, which posits that there are statistically significant differences in task performance based on the direction of numerical format processing (number words, written numerals, and nonsymbolic quantities) among primary school children (first, second, and third grade), attributes these differences to the grade-level variable.

To test this hypothesis, we conducted a one-way ANOVA based on numerical representations across four tasks: (1) number words → nonsymbolic quantities, (2) written Arabic numerals → nonsymbolic quantities, (3) number words → written numerals, and (4) written numerals → number words, with the independent variable being grade level (first, second, and third grade). Tables 3 and 4 present the results:

Table 3: Results of the one-way ANOVA for differences among primary school children (first, second, and third grade) across various numerical format-mapping tasks

Grade Levels (First Grade, Second Grade, and Third Grade – Primary School)	Source of Variation	Groups of Children	Sum of Squares	DF	Mean Squares	F Value	Sig
	Number Words → Non-Symbolic Quantity	Between Groups	86.8	2	43.4	43.504	0
		Within Groups	41.9	42	0.998		
		Total	128.7	44			
	Written Numerals → Non-Symbolic Quantity	Between Groups	67.511	2	33.756	31.228	0
		Within Groups	45.4	42	1.081		
		Total	112.911	44			
	Written Numerals → Number Words	Between Groups	469.911	2	234.956	74.91	0
		Within Groups	131.733	42	3.137		
		Total	601.644	44			
	Number Words → Written Numerals	Between Groups	808.844	2	404.422	103.74	0
		Within Groups	163.733	42	3.898		
		Total	927.578	44			

A careful examination of Table (3) reveals statistically significant differences between the groups across all variables at the 0.01 level. These include:

- From number words to non-symbolic quantities: $F = 43.504, p = 0.000$
- From written numerals to non-symbolic quantities: $F = 31.228, p = 0.000$
- From written numerals to spoken number words: $F = 74.910, p = 0.000$
- From spoken number words to writing Arabic numerals: $F = 103.740, p = 0.000$

Post hoc comparisons further indicated the presence of significant differences in tasks involving transformations between different numerical formats. The direction of these differences was determined using the Scheffé test, and Table (4) presents the direction and nature of these differences.

Table (4): Direction of post hoc differences in tasks involving various numerical format transformations among primary school children (first, second, and third grade)

Dimensions	Level (A)	Level (B)	Mean Difference	Sig
Number Words → Non-Symbolic Quantity	First Grade	Second Grade	1.6	0
	First Grade	Third Grade	3.4	0
	Second Grade	Third Grade	1.8	0
Written Numerals → Non-Symbolic Quantity	First Grade	Second Grade	4.46	0.476
	First Grade	Third Grade	2.8	0
	Second Grade	Third Grade	2.33	0
Number Words → Written Numerals	First Grade	Second Grade	1.26	0.16
	First Grade	Third Grade	7.4	0
	Second Grade	Third Grade	6.13	0
Written Numerals → Number Words	First Grade	Second Grade	2.31	0.231
	First Grade	Third Grade	9.53	0
	Second Grade	Third Grade	8.33	0

Upon examining the results of the post-hoc comparisons presented in Table (4), the following observations can be made:

- From number words to non-symbolic quantities: The differences between all pairs of grade levels are statistically significant (Sig = 0.000).
- From written numerals to non-symbolic quantities: There is no statistically significant difference between first and second grade (Sig = 0.476), suggesting that children at this stage are still in the process of learning the relationship between written numerals and their corresponding cardinal quantities. In contrast, statistically significant differences are observed between first and third grade (2.8, Sig < 0.001) and between second and third grade (2.33, Sig < 0.001). These findings confirm that by third grade, children have significantly improved their ability to associate Arabic numerals with their corresponding quantities.

- From number words to written numerals: There is no statistically significant difference between first and second grade (Sig = 0.160). This result indicates that the conversion from number words to written Arabic numerals remains unstable at this stage. However, statistically significant differences are observed between first and third grade (7.40, Sig < 0.001) and between second and third grade (6.13, Sig < 0.001), suggesting a marked leap in children's ability to use spoken number words and link them to their numeric representations.
- From written numerals to number words: No statistically significant difference is observed between first and second grade (Sig = 0.231), whereas significant differences are found between first and third grade (9.53, Sig < 0.000) and between second and third grade (8.33, Sig < 0.000). These results reflect a considerable improvement in the ability to convert Arabic numerals into number words.

The third hypothesis posits that the three numerical formats (verbal number words, written Arabic numerals, and non-symbolic quantitative representations) do not develop along a strictly linear trajectory; rather, the nature of their interrelationship is shaped by both the direction of numerical processing and the child's grade level.

To test this hypothesis, Pearson's correlation coefficient (r) was employed to determine whether consistent patterns exist among the different variables of numerical tasks at each grade level (first, second, and third grade). The results are presented in Table (5).

Table (5): Correlation coefficients between the different numerical tasks of the three numerical formats across the three grade levels

	Dimensions	1	2	3	4	5	6
First Grade	1. Number Words → Non-Symbolic Quantity	—					
	2. Written Numerals → Non-Symbolic Quantity	-0.283 0.306	—				
	3. Overall Performance in Number Mapping	0.598*** 0.019	0.600* 0.018	—			
	4. Number Words → Written Numerals	0.258 0.354	-0.399 0.141	-0.118 0.675	—		
	5. Written Numerals → Number Words	-0.135 0.632	-0.438 0.103	-0.479 0.071	0.287 0.300	—	
	6. Overall Performance in Numeral Decoding	-0.376 0.168	0.423 0.116	0.667** 0.007	0.136 0.629	0.833*** 0.000	—
Second Grade	1. Number Words → Non-Symbolic Quantity	—					
	2. Written Numerals → Non-Symbolic Quantity	0.726 0.002	—				
	3. Overall Performance in Number Mapping	0.921* 0.000	0.936* 0.000	—			
	4. Number Words → Written Numerals	0.601* 0.018	0.421 0.118	0.545* 0.036	—		
	5. Written Numerals → Number Words	0.303 0.273	0.265 0.341	0.304 0.270	0.863* 0.000	—	
	6. Overall Performance in Numeral Decoding	0.486 0.066	0.365 0.181	0.455 0.083	0.973* 0.000	0.956* 0.000	—
Third Grade	1. Number Words → Non-Symbolic Quantity	—					
	2. Written Numerals → Non-Symbolic Quantity	0.099 0.725	—				
	3. Overall Performance in Number Mapping	0.740** 0.002	0.742** 0.002	—			
	4. Number Words → Written Numerals	-0.089 0.752	***0.696 0.004	0.410 0.129	—		
	5. Written Numerals → Number Words	0.522* 0.046	0.029 0.919	0.371 0.174	-0.009 0.975	—	
	6. Overall Performance in Numeral Decoding	0.354 0.195	0.458 0.086	*0.548 0.034	*0.681 0.014	***0.780 0.001	—

Table 5 reveals the following:

- First Grade: The correlation results were largely non-significant across most tasks, suggesting that children at this age have not yet developed strong connections between the different numerical formats.
- Second Grade: The results show a marked increase in the strength of relationships between most tasks. A statistically significant correlation was observed between *written Arabic numerals* → *nonsymbolic quantities* and *number words* → *nonsymbolic quantities* ($r = 0.726, p = 0.002$), as well as between *number words* → *written numerals* and *written numerals* → *number words* ($r = 0.956, p = 0.000$). These findings indicate a notable improvement, reflecting the development of children's ability to use numbers and establish connections between them.
- Third Grade: The results suggest that children at this stage have reached a certain level of stability in their numerical skills. Some correlations decrease compared to second grade, with no significant relationships found between *written numerals* and *nonsymbolic quantities* or between *number words* and *nonsymbolic quantities*. This phenomenon may be attributed to the nature of the task used, which relies on estimating two-digit numbers. By this stage of development and schooling, children's numerical abilities may have surpassed the difficulty level of the task, prompting them to rely more on alternative, independent strategies. This interpretation is supported by the significant relationship between *number words* → *written numerals* and *written numerals* → *nonsymbolic quantities* ($r = 0.696, p = 0.004$). Finally, a significant correlation is also observed between *written numerals* and *number words*, and between *number words* → *nonsymbolic quantities* ($r = 0.522, p = 0.046$).

Taken together, these findings indicate that the development of numerical format representations and the connections between them vary according to both the direction of numerical processing and the child's grade level or age. The associations between numerical formats strengthen with age and educational experience. Consequently, this development is not fixed but is influenced by the type of numerical representation emphasized at each developmental stage, which in turn supports the acquisition of later numerical skills. Furthermore, this progression is nonlinear—advancement does not occur uniformly across grade levels, but rather shows variability due to multiple factors. These conclusions are consistent with the findings of Meyer (2015) and Kolkman et al. (2013).

III- Conclusion

This study aimed to analyze and investigate the developmental trajectories and acquisition of different numerical formats among primary school children. It focused on the nature and evolution of the relationships between these numerical formats across three successive grade levels, considering the role of increasing educational experience in mastering various numerical associations. It is worth noting that the school curriculum is generally designed in a progressive manner, and it is therefore expected that the results obtained in this study reveal differences across the three grade levels, reflecting the children's ongoing cognitive development.

The post hoc comparisons which served as the main tool to study developmental trends showed that children achieved statistically meaningful progress in their numerical skills across multiple areas. The students showed steady development in their ability to convert number words into non-symbolic quantities throughout all grade levels. Number transcoding tasks which require converting number words into written numerals showed a different developmental pattern because the first and second grades did not show any noticeable changes. The students showed major statistically significant progress when they reached third grade.

The research results support previous studies which show students need a long time to learn number transcoding rules because this process remains difficult throughout primary school until the upper grades (Maziane & Nouani, 2024, p. 20). The learning process demands fundamental place-value knowledge which functions as a base concept according to Fuson and Briars (1990).

The study of numerical task relationships between different grade levels reveals that numerical format development follows a non-linear pattern. The research shows that children learn to convert number words into symbols before they can match number words with written numbers. The relationship between written numbers and non-symbolic values reaches its final stage of development. The research by Hurst et al. (2017) and Jiménez-Lira et al. (2017) shows that number transcoding skills between words and digits help students learn how to connect written numbers with non-symbolic quantities. The research results demonstrate that number words and written numerals create a connection which helps children understand numerical quantities as they progress through age and education.

The research presents vital knowledge about how different numerical formats create connections which develop through time. The research results will help educational institutions develop learning programs which match student abilities and grasp their natural development in mathematics.

Referrals and References:

- [1]. Antell, S. E., & Keating, D. P. (1983). Perception of Numerical Invariance in Neonates. *Child Development*.
- [2]. Benoit, L., Lehalle, H., Molina, M., Tijus, C., & Jouen, F. (2013). Young Children's Mapping Between Arrays, Number Words, and Digits. *Cognition*, 129(1).
- [3]. Bialystok, E. (1992). Symbolic Representation of Letters and Numbers. *Cognitive Development*, 7(3).
- [4]. Brankaer, C., Ghesquière, P., & De Smedt, B. (2013). The development of numerical magnitude processing and its association with working memory in children with mild intellectual disabilities. *Research in Developmental Disabilities*.
- [5]. Carey, S. (2001). Cognitive foundations of arithmetic: Evolution and Ontogenesis. *Mind and Language*.
- [6]. Carey, S. (2004). Bootstrapping & the origin of concepts. *Daedalus*.
- [7]. Carey, S. (2009). Where Our Number Concepts Come From. *The Journal of Philosophy*, 106(4).
- [8]. Carey, S., Shusterman, A., Haward, P., & Distefano, R. (2017). Do Analog Number Representations Underlie the Meanings of Young Children's Verbal Numerals? *Cognition*, 168.
- [9]. Cheung, P., Rubenson, M., & Barner, D. (2017). To infinity and beyond: Children generalize the successor function to all possible numbers years after learning to count. *Cognitive psychology*.
- [10]. Dehaene, S. (1992). Varieties of Numerical Abilities. *Cognition*, 44(1).
- [11]. Dehaene, S. (1997). *The Number Sense: how the mind creates mathematics*. New York: Oxford University Press.
- [12]. Dehaene, S., & Changeux, J. P. (1993). Development of Elementary Numerical Abilities: A Neuronal Model. *Journal of Cognitive Neuroscience*, 5(4).
- [13]. Feigenson, L., Dehaene, S., & Spelke, E. (2004). Core Systems of Number. *Trends in Cognitive Sciences*, 8(7).
- [14]. Fuson, K., & Briars, D. (1990). Using a base-ten blocks learning/ teaching approach for first and second grade place-value and multi-digit addition and subtraction. *Journal for Research in Mathematics Education*.
- [15]. Geary, D. C., Hoard, M. K., & Bailey, D. H. (2012). Fact Retrieval Deficits in Low Achieving Children and Children With Mathematical Learning Disability. *Journal of Learning Disabilities*, 45.
- [16]. Hurst, M., Anderson, U., & Cordes, S. (2017). Mapping Among Number Words, Numerals, and Non-symbolic Quantities in Preschoolers. *Journal of Cognition and Development*, 18(1).
- [17]. Jiménez Lira, C., Carver, M., Douglas, H., & LeFevre, J. A. (2017). The Integration of Symbolic and Non-symbolic Representations of Exact Quantity in Preschool Children. *Cognition*, 166.
- [18]. Knudsen, B., Fischer, M., Henning, A., & Aschersleben, G. (2015). The development of Arabic Digit knowledge in 4 to 7 Year old children. *Journal of Numerical cognition*.
- [19]. Kolkman, M. E., Kroesbergen, E. H., & Leseman, P. P. (2013). Early numerical development and the role of non-symbolic and symbolic skills. *Learning and Instruction*, 25.
- [20]. Le Corre, M., & Carey, S. (2007). One, two three, four, nothing more: An investigation of the conceptual sources of the verbal counting principles. *cognition*.
- [21]. Lipton, J. S., & Spelke, E. S. (2005). Preschool children's mapping of number words to non-symbolic numerosities. *Child Development*, 76(5).
- [22]. Maziane, S., & Nouani, H. (2024). The Relationship Between Working Memory and Numerical Decoding Processes in Children. *Journal of Educational and Pedagogical Research*.
- [23]. Meyer, S. (2015). Numerical estimation in mathematical learning: Roles and benefits of mapping numerical representations at the developmental, educational, and re-educational level. *Doctoral thesis, Université de Charles de Gaulle – Lille*. Lille, France: Université de Charles de Gaulle – Lille.
- [24]. Mundy, E., & Gilmore, C. K. (2009). Children's mapping between symbolic and non-symbolic representations of number. *Journal of Experimental Child Psychology*, 103(4).
- [25]. Mustafa, I. (2012). Standardization of coloured progressive matrices on the palestinian context. Gaza, Department of psychology.
- [26]. Nieder, A., & Dehaene, S. (2009). Representation of number in the brain. *Annual Review of Neuroscience*, 32.
- [27]. Nouani, H. (2012). Language Disorders and Associated Cognitive Functions: The Case of Working Memory. *Journal of the Laboratory of Cognitive Sciences*.
- [28]. Nouani, H. (2018). *Orthophony and the Arabic Language: An Introduction to Speech Pathology*. Algiers, Algeria: Dar Al-Khaldounia.
- [29]. Piazza, M. (2010). Neurocognitive start-up tools for symbolic number representations. *Trends in Cognitive Sciences*, 14(12).

- [30]. Piazza, M., Facoetti, A., Trussardi, A. N., Berteletti, I., Conte, S., Lucangeli, D., & Zorzi, M. (2010). Developmental trajectory of number acuity reveals a severe impairment in developmental dyscalculia. *Cognition*, 116(1).
- [31]. Pica, P., Lemer, C., Izard, V., & Dehaene, S. (2004). Exact and approximate arithmetic in an Amazonian indigene group. *Science*, 306(5695).
- [32]. Raven, J. (2000). The Raven's progressive matrices: Change and stability over culture and time. *Cognitive Psychology*, 41.
- [33]. Sarnecka, B. W., Negen, J., & Goldman, M. C. (2018). Early number knowledge in dual-language learners from low-SES households. In K. S. Mix, S. C. Levine, & J. (. Huttenlocher, *Language and Culture in Mathematical Cognition* (1st ed.). Cambridge, MA: Academic Press.
- [34]. Sarnecka, B., & Carey. (2008). How counting represents number:What children must learn and when they learn it. *Cognition*.
- [35]. Sella, F., Berteletti, I., Lucangeli, D., & Zorzi, M. (2017). Preschool children use space, rather than counting, to infer the numerical magnitude of digits: Evidence for spatial mapping principle. *Cognition*.
- [36]. Short, D. S., & Mclean, J. F. (2023). The relationship between numerical mapping abilities, math achievement and socioeconomic status in 4 and 5 year old children . *British journal of education psychology* .
- [37]. Von Aster, M. G., & Shalev, R. S. (2007). Number development and developmental dyscalculia. *Developmental Medicine & Child Neurology*, 49(11).
- [38]. Von Aster, M., & Dellatolas, G. (2006). ZAREKI-R: Battery for the assessment of number processing and calculation in children. paris : Editions du centre de psychology appliquée (ECPA).
- [39]. Wynn, K. (1992). Addition and subtraction by human infants. *Nature*, 358(6389).