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Representations of Numerical Sequences in Mexican Secondary School Textbooks

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Abstract

The study of numerical sequences usually focuses on the use of symbols or finding generalizations, that is, a more formal notation. However, there is several research on the different representations, but little research in representations that we consider as drawings and illustrations and that, in general, are commonly used in textbooks when both a numerical sequence and a figurative sequence are shown. The present research with a qualitative approach sought to identify the representations of sequences contained in Middle school textbooks. Nine textbooks were analyzed using the theoretical-methodological proposal known as Mathematical Content Analysis, where 28 different figures were found to represent a numerical sequence. The findings showed that there are three types of representations in the textbooks analyzed: abstract figures, real figures, and pictorial figures. The results show that the representations that appear most frequently in textbooks are pictorial figures.

Keywords: Numerical Sequences, Representations, Mathematics Textbooks, Early Algebra, Secondary Education

Introduction

Numerical sequences are an important topic in the teaching and learning of

mathematics because it involves the development of skills or competencies such as conjecture, generalization, argumentation, validation, and visualization, among others (National Council of Teachers of Mathematics [NCTM], 2000). Although a several of research has already been done on the representations of numerical sequences, the topic has not been studied in depth, since there are several studies focused on reasoning, understanding and generalization of patterns, where it is evident that students and teachers manifest difficulties in solving mathematical situations that involve sequences (Ferrini-Mundy, Lappan & Phillips,1997; Walkowiak, 2014; Wilkie, 2021).

Currently, representations are used in mathematics teaching as a tool (Castro, 2013). The multiple representations of mathematical objects can help students give consistency to their thoughts and communicate their ideas (Faria, Viseu, Gomes & Aires, 2022). Also, they are related to processes of modeling, understanding, connection and creation of its meaning (Radford, 2014). According to NCTM (2000), children must learn conventional forms of representations, but they must also be guided to develop and create representations that support their learning. Asking students to analyze contexts and images offers opportunities for more students to experience success in algebraic thinking long before enrolling in a formal algebra course. Therefore, it is essential to implement activities in primary and secondary school to promote algebraic thinking (Walkowiak, 2014).

Lupiañez (2016) reports that contexts that involve figural patterns promote mathematical skills such as reasoning, generalization, visualization among other things, since objects can be visualized and interpreted in different ways.

Duval (2012) claims that the lack of understanding of representations necessarily causes a poor understanding of mathematical content and Faria et al. (2022) mention that exploring different representations is a way to tackle difficulties in understanding certain mathematical concepts.

That said, research into numerical sequences is an important topic in Mathematics Education, but the representations that researchers make when showing a numerical sequence is something very few researchers have asked themselves. The goal of this research was to identify the representations of numerical sequences in secondary school textbooks. In this sense, the study aimed at answering the following research question: What are the representations of numerical sequences in secondary school textbooks?

Literature Review

Research and educational proposals that adhere to the early algebra approach have considered the use of multiple representations to understand and reason about problems as evidence of learning (Medrano, Xolocotzin, & Flores-Macías, 2022).

The study of patterns and/or sequences offers students opportunities to make abstractions and generalizations (English & Warren, 1998; Radford, 2003; Rivera, 2010).

Radford (2003), for example, examined students' work with figurative sequence and found that they abstracted features from ostensive figural patterns (i.e., the abstract objects are contextually conceptualized in reference to the features of the given concrete objects), and actions performed on them to arrive at a generalization. On the other hand, in a later study on pictorial growth patterns (are defined as patterns that show the functional relationship spatially by use of either pictures, figures or objects which provides visual cues that can "explain and support pattern generalization") Rivera and Becker (2005) found that 26 of 42 preservice elementary and secondary school teachers predominantly used numerical reasoning rather than figurative reasoning to analyze patterns. Additionally, they observed that of the 26 teachers who used a numerical strategy, 17 generalized about patterns using pattern covariation analysis or recursive thinking. That is, they used the previous figure in a sequence to determine the next one. The researchers found that students who used geometric reasoning more than numerical reasoning were able to explain and justify the simpler or explicit formulas they developed through correspondence analysis.

Wilkie (2016) examined the functional thinking of 102 upper elementary students across different representations and found that students were able to generalize linear relationships using symbolic representations when the question was based on a figural growth pattern (23%), a pictorial figure with a tabular representation (25%), as well as a verbal representation related to real life (46%).

Likewise, Wilkie & Clarke (2016) investigated upper elementary students' (11-12 years old) visualization of growth patterns and their subsequent type and level of generalization in describing and representing each functional relationship. They also explored the potential for students to visualize the same pattern in multiple ways and create more than one functional rule in a descriptive or even symbolic way.

In the research carried out by Palatnik & Koichu (2017), they examined ninth grade students' mathematical meaning while working with a numerical sequence. Students first related pictorial and numerical representations to each other and then constructed algebraic representations.

Ozsoy (2018) investigated the type and precision of the visual representations that future teachers generate in the pedagogical solution of verbal problems. As a result of the research, the types of visual representations (schematic, i.e., charts, tree diagrams; and pictorial, i.e., geometrics forms) generated by future teachers were determined. The results suggest that preservice teachers with high spatial abilities can generate correctly structured schematic representations, while those with low spatial abilities had a tendency to generate pictorial representations.

In recent studies, Medrano et al. (2022) analysed representations such as drawings, diagrams, or idiosyncratic symbols, produced spontaneously by third grade students. There were significant increases in student performance on generalized arithmetic and functional thinking problems. It was found that the production of more sophisticated representations

was associated with better performance on functional problems, but not on generalized arithmetic problems.

Faria et al. (2022) carried out an investigation where they reported on students solving a sequence of tasks and showed that they preferred pictorial representations. The reason why pictorial representations were the most useful representations in the construction of meanings of the mathematical objects under study is that they allowed students to express their reasoning more confidently and clearly, as they provided visual support that mitigated the abstract nature of mathematical concepts and gave them meaning (Ozsoy, 2018).

Conceptual Framework

Representation

According to Goldin (2014), the term "representation" refers to visible or tangible productions such as a graph or even a formula (an external representation), people's mental or cognitive constructions (an internal representation), or even the act or process of inventing or producing representations.

That is, representations are symbolic, graphic notations or verbal expressions that name mathematical concepts and procedures, organized according to their characteristics, properties, and relationships in different representation systems (Lupiañez, 2016).

For this research we decided to consider drawings and illustrations in general as representations.

Pattern

The pattern is any situation repeated regularly (Steen, 1988; Stacey, 1989). Patterns are usually formed from a generating core; in some cases, the core repeats, in others the core grows regularly (Castro, 2013).

Creating and recognizing patterns is an important strategy in solving mathematical problems, especially in those cases in which the issues can be solved; examining special cases, organizing the data systematically, determining a pattern, and using the constructed pattern to obtain the answer (Stacey, 1989).

Sequence

The sequence is a list of figures or numbers that follow a rule, whose regular behavior is associated with a pattern (Nuñez-Gutiérrez & Cabañas-Sánchez, 2023). Sequences in natural numbers are conceptualized in two notions: that of an ordered set and that of an infinite process, where each term of the sequence has a following term. It has

also been recorded that the objective of sequences is to determine new terms related to the known initial terms of the sequence, to establish relationships between them and to discover new terms. For this purpose, recursive or functional strategies can be applied. Recursive techniques consist of finding the following numbers from the difference between them. The functional involves constructing a general correspondence rule that relates the position number to the term of the sequence (Rico Castro & Romero, 1996).

Method

This research adopted an exploratory qualitative approach as it attempts to explain a specific situation. In our case, this specific situation of study consists of the representations, such as drawings or illustrations, that secondary school textbooks contain when presenting a numerical sequence (Schmelkes & Schmelkes, 2012).

Data Collection

It is a research based on one of the dimensions of the theoretical-methodological proposal of pedagogical analysis proposed in Rico & Moreno (2016) known as "Mathematical Content Analysis". In this case, these are representations of numerical sequences.

The data source for the analysis was obtained from the Ministry of Public Education (SEP, by its acronym in Spanish), which produces the official secondary mathematics curricular documents, and nine textbooks approved by the SEP, thus guaranteeing that their contents align with the study plans and programs established for this school level (Nuñez-Gutiérrez & Cabañas-Sánchez, 2023).

The analysis of school mathematical content allows us to establish and organize the meanings of a mathematics topic through its conceptual structure, representation systems and modes of use (Nuñez-Gutiérrez & Cabañas-Sánchez, 2023). These components show the multiplicity of meanings that can be attributed to school mathematical concepts, which results from the notion of a particular organizer (Rico, 1997) whose development and implications are analyzed through components of didactic analysis that favor its study.

The research was carried out in three phases.

1. Review of secondary school mathematics curricular documents and textbooks in Mexico. In this first phase, the textbooks where it is to be analyzed are searched.
2. Selection of textbooks that address the topic of numerical sequences in the first (12-13 years old), second (13-14 years old) and third grade of secondary school (14-15 years old). In this phase, the topic to be investigated is identified, that is, on which pages it is located. See Table 1.

3. Content analysis based on the representations of drawings, photographs, and illustrations.

Table: 1 Selected textbooks

Degree	Editorials	Books analyzed	Figures of numerical sequences
First	Secretaría de Educación Pública	1	4
Second	Larousse, Grupo Editorial Patria, Santillana, Secretaría de Educación Pública	5	6
Third	Santillana, Secretaría de Educación Pública	3	18
	Total	9	28

In the Appendix the complete references of the selected textbooks can be seen.
Source: self-made

For the content analysis, in each book, we located the sections that addressed the topic of numerical sequences. Later, the different representations were identified. Finally, the different representations used to present the topic, exercise or task of numerical sequences were analyzed.

Results

In Mexico, the 2011, 2017 and 2022 mathematics study plan and programs (SEP, 2011; SEP, 2017; SEP, 2022) establish that sequences are studied during the three years of secondary school, through numerical and figural patterns in order to promote skills of construction, formulation and obtain the general rule of the sequence (Nuñez-Gutiérrez & Cabañas-Sánchez, 2023).

In the first grade (12-13 years old), the sequence where the difference between one term and the next is a constant is studied through common language such as: expression (general, formulas and rules), ordered set, progression, arithmetic sequence, geometric sequence, pattern, difference, general, and particular term.

In the second grade (13-14 years old), the arithmetic sequence obtains all its terms by adding a fixed number called difference to the previous one, except for the first term, that is, the general rule, algebraic expressions, numerical sequences, pattern, arithmetic sequences, term and difference are studied.

Finally, in third grade (14-15 years old), the geometric and algebraic representations of quadratic sequences are studied as second-degree equations in a general way. In this case, the increase in one of the variables is not proportional to the increase in

the other variable. Also, in this context, students study concepts like algebraic expression, term, consecutive, increment, regularities, constant, area, binomials, and variables.

Nuñez-Gutiérrez and Cabañas-Sánchez (2023) presented the concepts identified in the Mexican school curriculum on sequences in the following way.

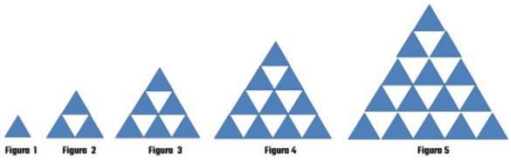
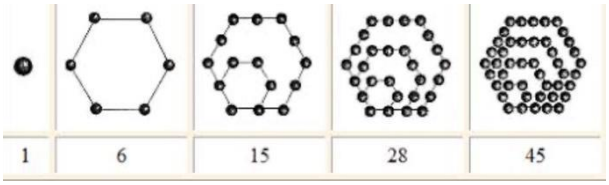
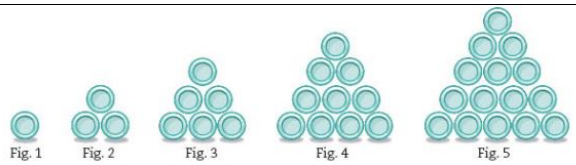
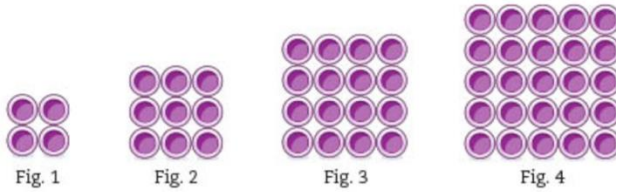
- First grade (12-13 years old). Numerical sequences.
- Second grade (13-14 years old). Sequences, arithmetic sequences, and linear sequences.
- Third grade (14-15 years old). Quadratic sequences.

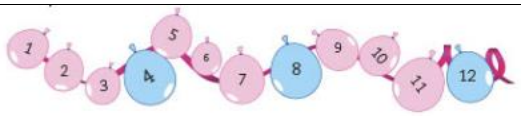
Classification of Representations

Three types of sequence representations were identified: abstract, pictorial, and real (Table 2).

1. Abstract representations. They are a mix of geometric figures, real figures, and figurative numbers. A figurative number is a specific configuration or arrangement of points that represents a number through a recognizable model or figure. They are primarily considered geometric figures in the plane or in space (Freudenthal, 1991). For example, see Figure 2.
2. Pictorial representations. They are representations through points of certain geometric configurations that represent a link between geometry and arithmetic (Eves, 1976). For example, see Figure 3.
3. Realistic representations. They are figures of objects and animals that we commonly find in our environment.

Table 2: Types of representations

Type	Number of figures	Image
Abstract figure	2	 ***Figure 1:*** From Matemáticas 3 (p.173), by M. Trigueros, M. D. López, M. I. Schulmaister, I. T. Sandoval, E. Jinich & M. Cortés, 2021, SEP. Copyright statement.  ***Figure 2:*** From Matemáticas tercer grado (p.162), by L. Briseño, G. Carrasco, P. Martínez, O. Palmas, F. Struck & J. Verdugo, 2006, SEP. Copyright statement.
Pictorial figures	22	 ***Figura 3:*** From Matemáticas tercer grado (p.34), by H.H. Balbuena, E. Escareño, F. Escareño, S. García & O.L. López, 2021, SEP (*https://www.conaliteg.sep.gob.mx/2022/T3MAA.htm#page/2*) . Copyright statement.  ***Figure 4:*** From Matemáticas tercer grado (p.33), by H.H. Balbuena, E. Escareño, F. Escareño, S. García & O.L. López, 2021, SEP (*https://www.conaliteg.sep.gob.mx/2022/T3MAA.htm#page/2*) . Copyright statement.

Real figures	4	 ***Figure 5:*** From Matemáticas segundo grado (p.55), by H.H. Balbuena, S. García & O.L. López, 2019, SEP (https://www.conaliteg.sep.gob.mx/2022/T2MAA.htm#page/2). Copyright statement.  ***Figure 6:*** From Matemáticas primer grado (p.157), by M.H. Cano, E. Flores, P.A. Salazar & M.M. Tlachy 2019, SEP (https://www.conaliteg.sep.gob.mx/2022/T1MAA.htm#page/157) Copyright statement.

Source: self-made

Findings

This research focused on identifying the representations of numerical sequences in secondary school textbooks. Based on the analysis of mathematical content, different representations of numerical sequences were identified in the three grades studied.

In the first-grade textbook that was analyzed only four representations were found, two are pictorial and two are realistic. In the five second grade textbooks analyzed, the representations found most frequently are realistic ones, they present balloons, frogs, etc. Finally, in the three third grade textbooks analyzed, the three types of representations were found, but more pictorial representations were found.

In total, 28 representations of numerical sequences were found in the nine mathematics textbooks analyzed. We find three categories of representations. The first category contains abstract figures that represent 7% of the representations found. The second category corresponds to pictorial figures, which yielded 78.6% and the third category includes realistic figures which represent 14.3%.

Therefore, the data indicates that one of the representations that is most used in the textbooks of the three grades in secondary school is the pictorial one. In relation to research on numerical sequences or patterns in other countries, aspects were identified that coincide with those found in this research (Rivera and Becker 2005; Castro, 2013; Wilkie, 2016; Nuñez-Gutiérrez & Cabañas-Sánchez, 2023).

On the other hand, the findings of this research show that pictorial representations are commonly used in textbooks, as Walkowiak (2014) mentions geometric or pictorial growth patterns that serve as a rich context to explore generalization. Some important advances in mathematics have arisen from the use of a pictorial model, from the creation

of powerful or ingenious iconic representations that, initially, functioned as externalized models of ideas that were already known (Castro, 2013).

From the results obtained, it was observed that the representations that are frequently found in Mexican textbooks of different study plans are the pictorial figures that have been present over the years, as well as in different research on the topic.

Conclusions

After having analysed the results of this research we can conclude that:

We were able to observe that, in the textbooks of any academic grade at the secondary level, regardless of the Mexican school curriculum, pictorial figures are always mostly presented to represent a numerical sequence.

According to the three types of representations found, pictorial figures were presented more frequently, and abstract figures were presented less frequently.

It is important that the information recorded in the Mexican school curriculum is evident in teaching practice and it is suggested to take advantage of other types of representations such as having students propose their own figures, or likewise, that designers propose other representations other than those poses in textbooks, so that students have diversity in representations.

However, one of the limitations of the study consists of the analysis of numerical sequences in the same structure, where it was observed that the sequences were increasing. It was also identified that the authors and designers of textbooks, for the most part, always present the first four terms of the sequence. It is also important to mention that in the most recent textbooks figures were no longer found to represent numerical sequences, although it is very important for students to have a representation to interpret and understand a sequence.

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APPENDIX

Mathematics textbooks selected for study:

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