2023, Retos, 48, 74-85

Spatial thinking skills mediated by communication processes in preschool children
Habilidades de pensamiento espacial mediadas por procesos de comunicación en niños y niñas de preescolar

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Resumen. Varios estudios han mostrado la relación entre habilidades matemáticas y habilidades de lenguaje. El objetivo principal de esta investigación consiste en identificar habilidades en pensamiento espacial, adquiridas a través de procesos de comunicación y, adicionalmente, identificar las habilidades de transmisión y recepción de información que logran los niños y las niñas en relación con el desarrollo de habilidades espaciales. Todo el desarrollo de esta investigación se lleva a cabo en el marco de la metodología de la Ingeniería Didáctica, a través de la cual se diseñaron cuatro Situaciones Didácticas (SD). El diseño es de tipo no experimental con un grupo establecido. La muestra está compuesta por un total de 73 niños y niñas de preescolar con edades entre cinco y seis años. Los resultados muestran que una vez adquirida la destreza de emitir y receptar mensajes, los estudiantes desarrollaron pensamiento matemático sobre su ubicación en el espacio de acuerdo a un sistema de coordenadas, además de la habilidad para dar instrucciones en las que aparecen relaciones de distancia, dirección y orientación
Palabras clave: lenguaje, comunicación, matemática, pensamiento espacial, ingeniería didáctica.

Abstract. Several studies have shown the relationship between math skills and language skills. The main objective of this investigation is to identify preschool children's spatial thinking skills, achieved through communication processes and also to identify the information transmission and reception skills acquired by children in relation to the development of spatial skills. The whole process of this research is based on the Didactic Engineering methodology, through which four didactic situations (DSs) were designed. The design is non-experimental with an established group. The sample consists of 73 preschool boys and girls aged between five and six years. The results show that once the ability to send and receive messages is acquired, students developed mathematical thinking about their location in space according to a coordinate system, as well as the ability to give instructions in which distance, direction, and orientation relationships appear.
Keywords: language, communication, mathematics, spatial thinking, didactic engineering.

Resumo. Vários estudos mostraram a relação entre as habilidades matemáticas e as habilidades linguísticas. O objetivo principal desta pesquisa é identificar habilidades de pensamento espacial, adquiridas por meio de processos de comunicação e, adicionalmente, identificar as habilidades de transmissão e recepção de informações que meninos e meninas alcançam em relação ao desenvolvimento de habilidades espaciais. Todo o desenvolvimento desta pesquisa é realizado no âmbito da metodologia da Engenharia Didática, por meio da qual foram delineadas quatro Situações Didáticas (DS). O projeto é não experimental com um grupo estabelecido. A amostra é composta por um total de 73 meninos e meninas pré-escolares com idades entre 5 e 6 anos. Os resultados mostram que uma vez adquirida a habilidade de emitir e receber mensagens, os meninos e meninas desenvolveram o pensamento matemático sobre estar localizados no espaço segundo um sistema de coordenadas, além da habilidade de dar instruções em que aparecem. relações de orientação
Palavras-chave: linguagem, comunicação, matemática, pensamento espacial, engenharia didática.

Fecha recepción: 27-05-21. Fecha de aceptación:13-01-23
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Introduction

Throughout the Greek and medieval traditions, there was already a distinction between how people performed mathematical tasks regarding the number: arithmetic, and how they performed mathematical tasks regarding space: geometry (Ministerio de Educación Nacional, MEN, 2006). Geometry is the exploration of space. From birth, the child explores space and gradually develops notions of perspective, distance, and depth (Bermejo, 2003; Dienes & Golding, 1982). Most abstract notions are learned in early childhood, thanks to movement (Vizcarra, Gómez-Pintado, Martínez-Abajo, & López-Vélez, 2022). The mastery of spatial relations, in turn, implies knowledge such as spatial orientation, the location of an object or person, the organization of displacements, the communication of positions and displacements, as well as the production and interpretation of flat representations of space (Quaranta & Ressia, 2009, as cited in Uribe, Cárdenas, & Becerra, 2014). We learn emotionally and conceptually by interacting with the spatial environment. Studies have shown that movement is crucial for any other brain function, including memory, emotion, language, and learning (Jensen, 2005, as cited in Arias & Fernández 2022).

According to MEN (2006) spatial thinking is a type of mathematical thinking, whereby mental representations of space objects, their relationships, transformations, and representations are constructed and manipulated.

Mathematics is the primary essence of thought, calculation, communication, and life itself. Therefore, throughout the history of mathematics, the only way to appreciate it was by learning to read its symbols (Devlin, 2003).

Several studies have shown the relationship between early math skills and language skills. When students are challenged to think and reason about mathematics and communicate the results of their thoughts to others orally or in writing, they learn to be clear and convincing. They communicate in order to learn mathematics and they learn how to communicate mathematically (NCTM, 2000, as cited in Wong, Graham, Hoskyn, & Berman, 2012).

Toll and Van Luit (2014) conducted a two-year study with kindergarten children using visual and verbal memory exercises, non-symbolic and symbolic comparison skills, and specific math-related language to explain the early arithmetic performance, and development of children with learning disabilities. The results showed a significant effect on these children's initial level of early arithmetic. Purpura and Ganley (2014) showed that language has a strong relationship with early mathematical skills. They found that non-mathematical factors such as memory and language are also closely related to mathematical development. They worked with a total of 199 kindergarten children aged four to six years who were assessed to measure their math skills as well as their working memory and language. The results indicated that the working memory has a specific relationship with the acquisition of mathematical tools, while language is also closely related to these early skills.

On the other hand, Verdine, Irwin, Golinkoff, and Hirsh-Pasek (2014) claimed that the executive functions, spatial skills, and mathematical skills are an important basis for math performance and may represent ways to improve school preparation for mathematics. According to Mezcua, Ruiz, Ferreira, and Martínez (2019), regular physical activity can improve memory, and mathematical and linguistic reasoning. Purpura, Napoli, Wehrspann, and Gold (2017) randomly allocated 47 children either to a group that received an intervention focused on mathematical language or to a group in which the usual methodology was followed. Their results showed that students in the intervention group obtained significantly better results than students in the control group, concluding that increased exposure to mathematical language can positively affect math skills.

Moreover, Cantin, Gnaedinger, Gallaway, Hesson-McInnis, and Hund (2016) wondered how reading and mathematical components operate in the formation of the child's mind, concluding that the symbology and construction of meanings required for reading are also important for mathematics and the comprehension of mental processes. Hence, their study defines mathematics as a central paradigm within the academic curriculum, which is necessary for many everyday life tasks. Several cognitive processes, such as short- and long-term memory, information-processing speed, and phonological processes, are supported by math abilities. An appropriate approach to math during preschool is a good predictor of primary and secondary school: a successful mathematical process in a four-year-old predicts a successful response when the child is six years old. Kyttälä, Aunio, Lepola, and Hautamäki (2014), in a study with 116 children aged between 4 and 7 years, noted that, although verbal memory does not have a direct effect on the resolution of verbal problems, it is indirectly related to their comprehension through vocabulary and auditory comprehension. Their results suggest that, in young children, verbal working memory resources support language skills, which, in turn, contribute to the solution of verbal problems.

Finally, Bresgi, Alexander, and Seabi (2017) conducted a study with 80 second-graders in schools in South Africa, finding a relationship between viso-spatial memory and math competencies. However, it is important to point out that, although the development of the initial knowledge of arithmetic is influenced by a series of non-mathematical factors— especially linguistic skills—, many of the works carried out on the relationship between language and early arithmetic have used general language measures. In that sense, Purpura and Reid (2016) conducted a study to determine the variance in the prediction of arithmetic performance using both general language measures and specific measures of mathematical language. Their results indicated that mathematical language was a significant predictor of arithmetic performance.

In general, the research discussed so far shows the relationship between linguistic skills and mathematical performance. In addition, through a dynamic methodology, children can perceive mathematics in a more striking and captivating way, practicing sensory and motor activities that allow them to enhance mathematical thinking (Fortes, 2016, as cited in Otero & Lafuente, 2022).

From the constructivist point of view, students' interaction with a given setting is essential for constructing their knowledge. Therefore, we will use the theory of Didactic Situations (DSs) to control the relationships between the student and the setting (Artigue & Perrin, 1991). Brousseau's (2007) theory of DS offers a way to work with preschool children to achieve communication processes. Brousseau states that, when he was a math student in the 1960s, he also attended Psychology classes. There, he began to wonder: in what circumstances does a person need specific mathematical knowledge to make certain decisions? And how do you explain in advance the reason why he would make these decisions? These questions led him to construct what is known as the theory of DSs. In his Psychology classes, Brousseau analyzed how Piagetian devices showed that children could adapt by developing mathematical knowledge, concluding that ultimately, students' behavior is what reveals how the environment works. Therefore, the environment plays an important role in helping students to develop mathematical knowledge. Vergara-Torres, Juvera-Portilla, Ceballos-Gurrola, and Zamarripa (2020) studied the relationship between the Pokémon GO video game and spatial orientation. In this case, communication was carried out through mobile phones in which their users had to go for a walk to comply with the game's objectives. The results showed improvement in spatial orientation and socialization skills.

In our research, DSs were designed that involve communication and spatial thinking, so that whoever receives the communication must decode it and execute it through spatial skills (see Figure 1).

To design the DSs, we use the Didactic engineering methodology that is extensively explained in the methodology section.

The following competences concerning spatial and geometric thinking are established by the MEN: recognizing horizontal and vertical, right and left, giving and following instructions that include the relationships of distance, direction, and orientation, and, finally, using coordinate systems to specify locations and describe spatial relationships (MEN, 2006).

The main objective of this research is to identify preschool children's spatial thinking skills achieved through communication processes, and also to identify their acquired information transmission and reception skills related to the development of spatial skills. We intend to use didactic situations that involve skills of emission and reception of information and, through the decoding of that information, to observe the development of spatial skills.

Methodology

This research is based on the Didactic Engineering methodology, through which four DSs were designed. The design is non-experimental. This research methodology is part of the so-called design experiments in educational research. Didactic design includes all kinds of "controlled intervention" research on the planning, delivery, and evaluation processes in mathematics education (Burkhardt & Schoenfeld, 2003, as cited in Artigue, 2009). A controlled intervention is an experimental design to control the learning process by which the student will achieve results (Powers 1973, 1978, as cited in Steffe & Thompson, 2000). We needed models that would explain the students' progress

According to Artigué (2009) in didactic engineering, validation is based on the comparison of an a priori analysis and the retrospective analysis of the corresponding DSs. Didactic engineering is summarized in three phases: (a) conception and a priori analysis of the Ds, (b) experimentation, and (c) retrospective analysis and evaluation (Artigué & Perrin, 1991). In the Conception stage, the investigator decides to act on a certain number of variables that determine the engineering organization. The validation process starts at this point, through the a priori analysis of the DSs resulting from these decisions. The objective of the a priori analysis of a DS is to determine how the global and local choices lead to the students' internal control; that is, the control of their behavior's meaning. It aims to show that the expected behaviors—if they appear—are the result of the knowledge that the didactical situation seeks to develop (Artigué & Perrin, 1991). Therefore, all the DSs have two components: the first is the symbolic language, and the second, the development of mathematical thinking concerning spatial ability. Children are expected to acquire a behavior defined by the ability to place themselves in space using structured instructions according to a symbolic language (ie. A card displaying a direction arrow) and a previously defined grammar. Hence, there is a transmitter of a previously written code and a receptor who decodes the instructions and performs them, thereby confirming that he has developed the spatial skill.

Participants

The Colombian educational system comprises initial education (attended in comprehensive education centers or CDI), preschool education, basic education, secondary education, and higher education. The present research was conducted in public schools serving preschool children (MEN, 2020).

The sample consists of 73 preschool children aged between five and six years, belonging to three groups of schools in the municipality of Neiva (Colombia). These schools belong to the lowest socioeconomic levels of the population. In general, about 50% of the total population of Neiva is described as poor and vulnerable (Fajardo & Gonzalez, 2007). The three groups have similar characteristics and to differenciate them, herein will be named as group one, comprising 23 children, group two, comprising 22 children, and group three 28 children.

Procedure

The success of communication is rated as follows: each action of receiving or transmitting or of not doing so was represented by T (transmits), R (receives), NT (does not transmit), or NR (does not receive). Transmitting and receiving are considered successful when the receptor achieves the goal or finds the prize. The means of all the percentages of transmitters and receptors in each of the DSs were calculated using the registers of all the groups. Four DSs were designed:

DS "Treasure Hunt." In this DS, the children should find a treasure, following their partner's explanations.

DS "Toy Conquest." In this DS, the children conquer toys by placing themselves on a grid representing the Cartesian plane according to the color and the animal.

DS "Discover the Hidden Letter." In this DS, the children must discover cards in the place indicated on the grid until they form the figure of a letter.

DS "The Freight Train." In this DS, the children should "load a train" according to their partner's instructions.

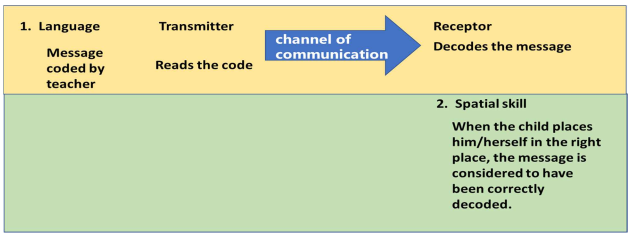

Figure 1. Components of the Didactic Situations

Each DS has two components: the first is the symbolic language, and the second is the development of mathematical thinking concerning spatial ability. Children are expected to develop the ability to place themselves in space, using instructions structured in a symbolic language, and a previously defined grammar. There is a transmitter of a code previously written by the teacher and a receptor who decodes and performs the instructions, developing spatial skills according to the diagram in Figure 1.

During the performance of the DS, a record of the successful transmitters and receptors is made. The information is presented in tables, following the code in Table 1.

Table 1.
Information Codes

Does not receive the order correctly	N R (Does not Receive)
Does not transmit information correctly	NT (Does NoTransmit)
Receives the order correctly	R(Receives)
Transmits information correctly	T (Transmits)

Data Analysis

Data analysis was performed in two phases. Initially, the percentage of success as transmitter and receptor were estimated with Excel. Then, the data were corroborated with the decisión-tree technique to prevent possible interpretation biases.

The following statistical analyses were carried out using the Excel program:

Percentage of successful children as a transmitter - Summary: We counted the Ts in each of the DSs and each group.

Percentage of successful children as a receptor - Summary: We counted the Rs in each of the DSs and each group.

We counted the Ts and Rs of each child in each group to evaluate the percentage of successful transmitters or receptors in each of the DSs.

After creating the registers, we calculated the respective percentages of success of each of the groups. We obtained the mean of all the percentages of the transmitters and receptors in each of the DSs with the registers of all the groups.

After calculating percentages in Excel, each of the SDs was interpreted with the decision-tree technique.

Decision-trees are a prediction model whose main objective is inductive learning from observations and logical constructions. It is a procedure similar to rule-based prediction systems, which are used to represent and categorize a series of conditions that occur successively to enable the solution of a problem (Bassols, Ovalle, & Rodríguez, 2021).

That is, a decision-tree presents a guide to arrive at possible outcomes from a series of decisions. A decision-tree starts with a single node, but then branches out into different outcomes or categories.

To generate decision-trees automatically, we used the unsupervised technique of Machine Learning decision-trees, which makes predictions or returns a result based on the data delivered to the algorithm. In this case, the results obtained in the experiment were used to feed the algorithm and thus build the decision-trees.

Firstly, the data were modified as follows to improve the performance of the decision-tree.

1. Tables 2, 3, and 4 of the records of each of the groups in the four DSs were merged.

2. As the model cannot distinguish two columns with the same name, the first four columns contain the data of the transmitter (T) and the last four, those of the receptor (R). Thus, the columns were named as follows: T Discover hidden letter, T Treasure hunt, T Toy Conquest, T Freight Train, and R Discover hidden letter, R Treasure hunt, R Toy Conquest, R Freight Train.

3. In Table 5, the values NT and NR were changed to 0, and T and R were changed to 1 (see Appendix).

The "Data Augmentation" strategy was used to obtain more data without performing more experiments with the students. Thus, each row is repeated twice, allowing the artificial intelligence model to better explain the patterns of the data.

To design and predict with the decision-tree, a tree is built for each DS, as illustrated in Figure 5. The tree was designed so that, knowing a student's result as the transmitter (T) of the message, it would predict the student's result if they were a Receptor (R). For example, if a student obtains the value of 1 as transmitter in "Discover the hidden letter," the model can predict whether this student will obtain 1 or 0 as receptor.

Tables 2, 3, and 4 show the records of each of the groups in the four DSs (see Appendix).

Results

Results of the Counting and Percentages of Transmitters and Receptors

In this section, we have graphically organized the achievements in all three groups to provide an overview.

Figure 2 shows the mean percentages of success of all three groups as transmitters. It can be seen that, conjointly, they all reached a mean success rate between 75% and 93%, with "Toy Conquest" being the DS that included more successful transmitters.

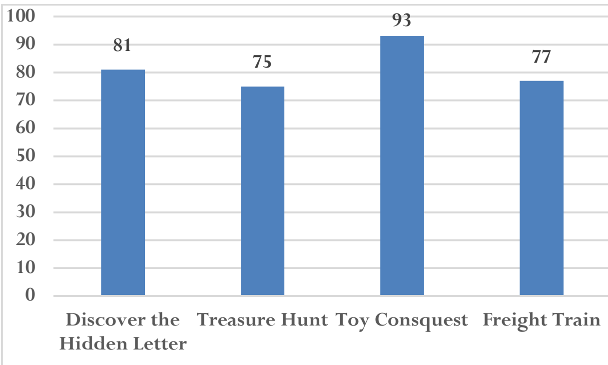

Figure 2. Summary of the Percentage of Successful Transmitters in Each of the Didactic Situations

Figure 3 shows the mean percentages of success of the three groups as receptors. On average, successful reception of information was between 56% and 93%, and again, the Toy Conquest was the DS that included the most successful receptors. Readers are reminded that, in the first three DSs, decoding the instructions implies performing them by means of spatial skills.

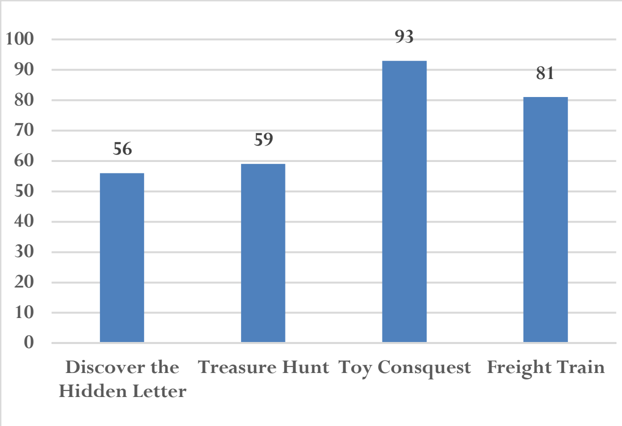

Figure 3. Summary of the Percentage of Successful Receptors in Each of the Didactic Situations

Figure 4 presents the results of the successful transmissions and receptions of the three groups in the four DSs. The "Toy Conquest" was the DS with the highest number of successful children both in the transmission and reception of information. It is also observed that the DS "Freight Train" obtained similar results, above 60% in all three groups.

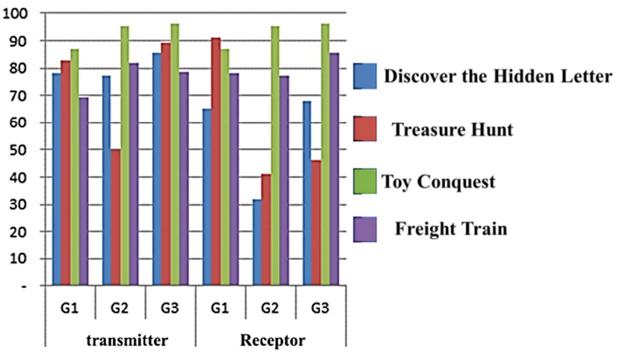

Figure 4. Results of the Successful Transmissions and Receptions of the Three Groups in the Four Didactic Situations

Results with the Decision-Tree Technique

Figure 5 shows a decision-tree graphic that asks a question that can be answered true or false and then continues to the base of the tree and finds the answer. The most important aspects to take into account are marked in green (figure 5).

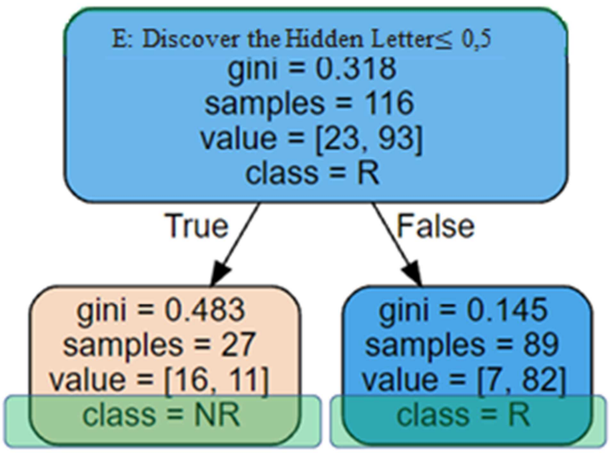

Figure 5. Example of a Decision-Tree for Each of the DSs

The additional values in each node show extra information that the algorithm used to construct the decision-tree. The Gini value represents the classification criterion of the values to sort the data at each step. The sample represents the amount of data that falls into each category. For example, 89 of the 116 results in each game belong to category R. Finally, values represent the range of values per sample. Likewise, after building the tree, the program shows the score that represents the number of correct answers when using the respective tree on the data set.

To interpret it, imagine that a new student is a transmitter (T) in the game "Discover hidden letter." T is represented by the value 1 (if the student were NT, the value would be 0), and we look at the question in the upper block **T:** Discover hidden letter <0.5. As 1 is greater than 0.5, we go down to the "False" branch on the right, where we find that the class is R. Therefore, a student who transmits (T) will also receive (R) in "Discover hidden letter;" that is, he will be a good receiver, according to the tree's prediction.

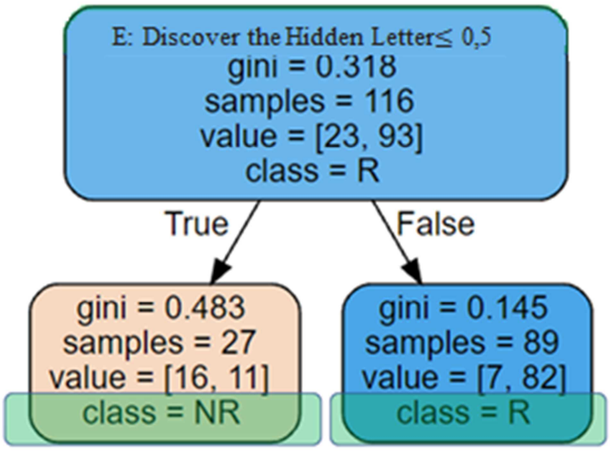

Figure 6. Decision-Tree for Discover the Hidden Letter

Building the trees for each of the DSs, in all the DSs, if someone transmits well (T), that person will also receive well (R). However, if that person does not transmit well (NT), they will not receive well (NR). This is shown in the following trees for each DS (figure 6).

Obtained a 0.63 score, which means that the tree classified them with a probability of 63% (figure 7).

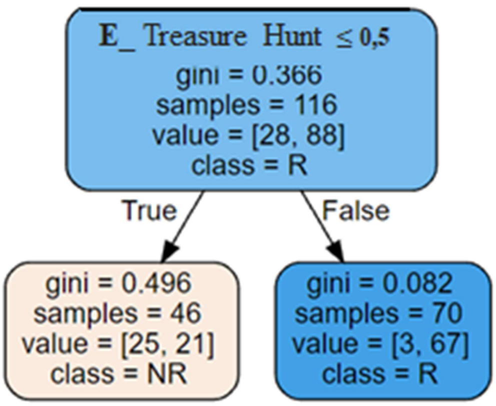

Figure 7. Decision-Tree for Treasure Hunt

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Has a 0.60 score, which means that the tree classified them with a probability of 60% (figure 8).

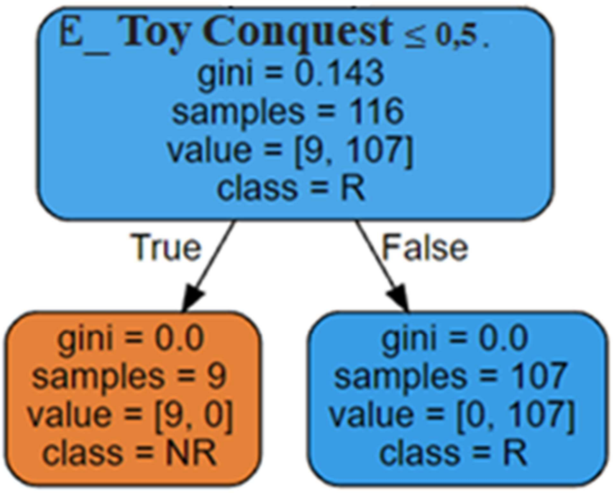

Figure 8. Decision-Tree for Conquest of Toys

Has a 1.0 score, which means that the tree classified them with a probability of 100% (figure 9).

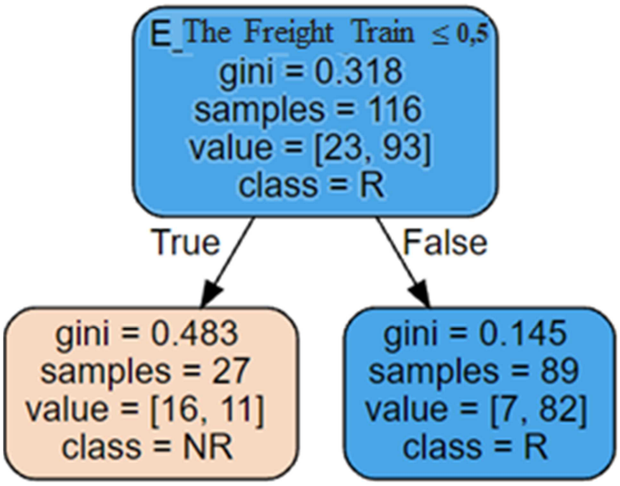

Figure 9. Decision -Tree for Freight Train

Has a 0.83 score, which means that the decision-tree classified them with a probability of 83%

The above was the first attempt. More columns were added to improve the performance of the "Treasure Hunt" decision-tree. For this purpose, the transmission results in the four games were used to predict the reception in "Treasure Hunt." (figure 10).

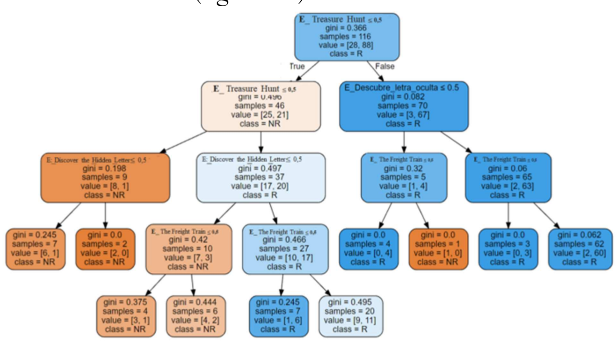

Figure 10. Reception Prediction in "Treasure Hunt"

This one has a score of 0.80, which means that at 80%, X is ranked much better than the former 60%, with a single question.

Comparison of the Results of the Two Techniques

According to this result, the results based on the decision-tree are very close to the results yielded with the statistical technique:

Discover the hidden letter: 81% and 63% with the decision-tree; Conquest of toys 93% and 100% with the decision-tree; Freight Train 77% and 83% with the decision-tree; and finally, Treasure Hunt, which came closer to the 75% initially obtained in the count with Excel, increasing by 80% when predicting with the 4 games, coming close to the 75% obtained in the count with Excel.

Discussion

Returning to Figure 3, which summarizes the successful reception in each of the DSs, we can observe that the mean percentage of success of the three groups as receptors is between 56% and 93%. Receiving information implies decoding the instructions and performing them through spatial skills; that is, this percentage of children managed to acquire the skills that were developed through the respective DSs. These results confirm those of other authors such as Santiuste and González (2014) and Wong et al. (2012) about the development of communication and thinking in children, as well as the relationship between math skills and language skills, as found by Purpura and Ganley (2014). Likewise, the studies of Purpura et al. (2017) have shown that increased exposure to mathematical language can positively affect children's mathematical skills.

Figure 4 shows the differences in the results of each of the DSs of the three groups. We highlight that Group one was more successful at receiving the information. In this group, out of the four DSs, only one DS showed poorer receptor results. There was a difference in the DS "Treasure Hunt", as Groups two and three obtained worse receptor results. The cause of this difference is probably the lack of space-oriented activities in these two groups. In the case of Group two, this was due to the difficulties in maintaining discipline when performing activities outside the classroom. In the case of Group three, it was due to their inflexible schedules, allowing few activities outside the classroom. These results are consistent with the work of Santiuste and González (2014), who have pointed to contextual factors, such as teaching strategies and teacher styles, in mathematical learning difficulties. In Group three, it was observed that activities outside the classroom were used infrequently as teaching strategies. The children tended to work only in their workbooks, which influenced their low skill in spatial orientation. Teacher styles may have also influenced these results in the sense that, to work away from the usual work place, the teacher should be able to dominate the group. This skill is more pronounced in teachers who continually perform the kind of work that require the development of spatial skills (i.e., dancing or sports). Football players must also know how to perceive information from the environment to manage the game space and adopt flexible actions in response to the unpredictability of game situations (Gréhaigne & Godbout, 1995, as cited in Oliveira et al., 2022).

The game of Treasure Hunt presents a DS in which the children dictate instructions to the teacher to color a large grid on the blackboard and, at the same time, the children can color a smaller grid at their workplace. In this game, the children of all three groups acquired the ability to transmit information; that is, to give instructions related to distance, direction, and orientation, such as right and left, up and down. We note that in Group one, more than 90% of the children also learned how to use those notions to move around and locate places in a broader space. This result coincides with the studies of Verdine et al. (2014) about the link between spatial skills and mathematical skills and, similarly, with the work on the viso-spatial memory and the mathematical skills of Bresgi et al. (2017).

The good disposition achieved for the approach to mathematics through the rigorous selection of the DSs confirms the studies on reading and mathematics of Pinto, Bigozzi, Tarchi, Vezzani, and Accorti (2016). According to them, children's good disposition to pronounce words, spell, construct sentences, and express themselves has to do with a successful approach to mathematical thinking. Santiuste and González (2014) also indicate affective factors such as motivation and the feeling of self-efficacy in the difficulties of learning mathematics. Our research always sought to prepare the children for the new challenges, and we carefully observed their compliance with the situations of action, formulation, and validation, according to Brousseau's theory of DSs.

On the other hand, the results of the DS "Toy Conquest," where there were more successful children both as receptors and transmitters, confirm the studies of Carpenter and Moser (1984, as cited in Wong et al., 2012) who claimed that the link with previously learned concepts contributes to children's deep conceptual understanding. In this case, the schema of this game was the basis for both the DSs "The Freight Train" and "Discover the Hidden Letter." This schema contributed to the children's success in these DSs, as they managed a schema that was already familiar to them. Thus, popular games are a didactic resource that have contributed to the improvement of motivation, satisfaction, cooperation, and climate in the classroom (López, Pozo, Fuentes & Bujez, 2019).

In the DS "Toy Conquest," the child should use a system of coordinates to locate and describe spatial relationships. Although this skill is addressed in the last elementary courses, it was achieved by most of the children of the three groups in our study. Toll and Van Luit (2014) refer to the importance of skills in a specific language related to mathematics to explain early mathematical performance. In this case, between 87 and 93% of the children in our study acquired the ability to place themselves in the first quadrant of the Cartesian plane, despite this being an activity that is commonly addressed with older children. It was essential for all the children to do the activities simultaneously, like a small replica, on a piece of paper, so that they all performed the same activity, which may have boosted the success rate.

As for the DS "Treasure Hunt," at the beginning, the previously drawn symbols (arrows) were given to the groups. This positively influenced the action because, as they did not spend time drawing the symbols, the children concentrated directly on encoding the message. This is consistent with the investigations of Piaget (1953/1994) on the difficulties of the preoperative stage for the child to be able to mentally represent a plane or any object. It is also related to the research of Yang et al. (2017) on the development of the multi-tasking capacity throughout childhood. Their results showed that, even at 12, children have not yet attained the ability to organize complex and varied tasks.

However, strategically, we finally delivered the code or sequence of symbols with the paths previously defined by the teacher to avoid the indiscipline generated by the long wait while the transmitter repeated the coding of the message. This drawback is explained in Piaget and Inhelder's (1967/2013) research, showing that 4-to-6-year-olds can organize objects according to a general pattern of a model, but they do not pay much attention to how the adjacent elements are arranged (AB or BA).

As for the DS "Discover the Hidden Letter," there were more children who successfully transmitted in all three groups. This DS is based on the "Toy Conquest" but it has more variables. The child who manages it has a smaller grid, but the receptor is guided by a large grid that is on the floor. This implies that, in addition to handling several variables simultaneously, the child is managing a much broader space, making it harder to focus on the details. This relates to the concepts of Gálvez (1985, as cited in Chamorro, 2005) on the micro-space related to interactions with smaller objects, and the meso-space where one interacts with broader spaces. Pinker (2010) also explains that, as the floor moves away from our feet, it projects an image that goes from the bottom to the center of our visual field, which makes us see different lengths and widths. Therefore, it is very likely that these details will influence the difference in results between the receptor and the transmitter.

The result of our investigation is validated because the expected behaviors were the result of the knowledge that the DSs sought to develop; that is, the ability to place themselves in space using structured instructions expressed in a symbolic language and a previously defined grammar. In the three groups, between 56 and 93% of the receptors decoded and executed the instructions, thereby showing the development of spatial skills. On the other hand, according to Santiuste (2014), the expressive function has to do with the person's need to express thoughts, knowledge, or experiences outwardly. Therefore, we controlled the children's engagement in each game so that they felt the need for communication because they had to communicate in order to win and achieve results for their team.

According to Artigue and Perrin (1991), in didactic engineering, validation is essentially internal, as it is based on the confrontation between an a priori analysis and a retrospective analysis of the corresponding DSs. It attempts to show that the expected behaviors, if they appear, are really the result of the knowledge that the situation seeks to develop.

Finally, research shows that language processes underlie the acquisition of spatial thinking skills in preschool children. The DSs implemented showed that, after acquiring the skill of transmitting and receiving messages, the children developed mathematical thinking about placing themselves in space according to a system of coordinates and using that coordinate system to specify locations and describe spatial relationships. They also acquired the ability to give instructions concerning the relationships of distance, direction, orientation, and recognition of the meaning of right and left. These results are in line with the competences established by the MEN (2006) regarding spatial and geometric thinking.

Conclusion

The results of our research show that a high percentage of the participating children manage to achieve the skills of placing themselves in space according to the coordinates, which are determined by the name of an animal and a color, and also the ability to give instructions concerning distance, direction, and orientation relationships.

In terms of identifying the transmission and reception skills that children achieve while developing spatial skills, the four DSs allowed the children to develop the ability to transmit, decode, and receive information.

These results are important because the achievements acquired are the result of the knowledge that the DS sought to develop; that is, the ability to locate oneself in space through instructions structured in a symbolic language and a previously defined grammar. The children managed to read a symbolic language related to distance, direction, and orientation and then receive that information by decoding and executing the order issued.

Limitations and New Avenues of Research

One of the main problems in research involving spatial thinking games in mathematics classes is that parents feel that their children are not learning mathematics because the numbers that are the commonly known symbols in mathematics are not involved. In addition, for the children to acquire these skills, they must perform similar activities many times. Geometric thinking has also been reduced in the first grades to memorizing the names of geometric figures while ignoring the importance of constructing these mental representations through the conquest of space and objects.

Finally, this research opens door for future work where other variables such as gender can be considered. It would also be interesting to increase the sample by involving dancing and physical education teachers.

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Appendix

Tables 2, 3, and 4 Show the Records of Each Group in the Four Didactic Situations

Table 2.
Records of Group One

No	Student	Discover Hidden Letter	Treasure Hunt	Toy Conquest	Freight Train	Discover Hidden Letter	Toy Conquest	Treasure Hunt	Freight Train
1	Student 1	T	T	T	T	R	R	R	R
2	Student 2	T	T	T	N T	R	R	R	N R
3	Student 3	T	T	T	T	R	R	R	R
4	Student 4	T	T	T	T	R	R	R	R
5	Student 5	T	T	T	T	R	R	R	R
6	Student 6	T	T	T	T	R	R	R	R
7	Student 7	T	T	T	T	R	R	R	R
8	Student 8	T	T	T	N T	N R	R	R	R
9	Student 9	T	T	T	T	R	R	R	R
10	Student 10	T	T	T	T	R	R	R	R
11	Student 11	T	T	T	T	R	R	R	R
12	Student 12	T	T	T	T	R	R	R	R
13	Student 13	T	T	T	T	N R	R	R	R
14	Student 14	T	T	T	T	N R	R	R	R
15	Student 15	T	T	T	T	R	R	R	R
16	Student 16	N T	N T	N T	N T	N R	N R	N R	N R
17	Student 17	N T	T	T	N T	N R	R	R	R
18	Student 18	T	T	T	T	R	R	R	R
19	Student 19	N T	N T	T	N T	R	R	R	N R
20	Student 20	T	T	T	T	N R	R	R	R
21	Student 21	N T	N T	N T	N T	N R	R	N R	N R
22	Student 22	T	T	T	T	R	R	R	R
23	Student 23	N T	N T	N T	N T	N R	N R	N R	N R

Table 3.
Records of Group Two

N°	Student	Discover Hidden Letter	Treasure Hunt	Toy Conquest	Freight Train	Discover Hidden Letter	Toy Conquest	Treasure Hunt	Freight Train
1	Student 1	T	T	T	T	R	R	R	R
2	Student 2	T	T	T	T	R	R	R	R
3	Student 3	T	T	T	T	N R	R	R	R
4	Student 4	T	N T	T	T	N R	N R	R	R
5	Student 5	T	T	T	T	N R	N R	R	R
6	Student 6	T	N T	T	T	R	N R	R	R
7	Student 7	T	N T	T	N T	N R	N R	R	N R
8	Student 8	T	T	T	T	N R	R	R	R
9	Student 9	T	T	T	T	R	N R	R	R
10	Student 10	T	T	T	T	R	R	R	R
11	Student 11	N T	N T	T	T	N R	N R	R	R
12	Student 12	T	N T	T	T	N R	N R	R	R
13	Student 13	T	T	T	T	N R	R	R	N R
14	Student 14	N T	N T	T	N T	N R	N R	R	N R
15	Student 15	T	T	T	T	R	R	R	R
16	Student 16	N T	N T	T	N T	N R	N R	R	N R
17	Student 17	T	N T	N T	N T	N R	N R	N R	N R
18	Student 18	T	T	T	T	N R	R	R	R
19	Student 19	T	T	T	T	R	R	R	R
20	Student 20	N T	N T	T	T	N R	N R	R	R
21	Student 21	T	N T	T	T	N R	N R	R	R
22	Student 22	N T	N T	T	T	N R	N R	R	R

Table 4.
Records of Group Three

No	Student	Discover Hidden Letter	Treasure Hunt	Toy Conquest	Freight Train	Discover Hidden Letter	Toy Conquest	Treasure Hunt	Freight Train
1	Student 1	N T	T	T	T	R	N R	R	R
2	Student 2	T	T	T	T	R	R	R	R
3	Student 3	T	N T	T	T	R	R	R	R
4	Student 4	T	T	T	T	R	R	R	N R
5	Student 5	T	T	T	T	R	R	R	N R
6	Student 6	T	T	T	T	N R	R	R	R
7	Student 7	T	T	T	T	N R	R	R	R
8	Student 8	T	T	T	T	R	R	R	R
9	Student 9	T	T	T	T	R	R	R	R
10	Student 10	N T	N T	T	T	R	R	R	R
11	Student 11	T	N T	T	T	N R	R	R	R

12	Student 12	T	N T	T	T	R	R	R	R
13	Student 13	T	N T	T	N T	N R	R	R	R
14	Student 14	N T	N T	N T	N T	N R	N R	N R	R
15	Student 15	T	T	T	T	R	R	R	R
16	Student 16	T	T	T	T	R	R	R	R
17	Student 17	N T	T	T	N T	N R	R	R	N R
18	Student 18	T	N T	T	N T	N R	R	R	R
19	Student 19	T	N T	T	T	N R	N R	R	R
20	Student 20	T	N T	T	N T	N R	R	R	R
21	Student 21	T	N T	T	N T	R	R	R	R
22	Student 22	T	N T	T	T	R	R	R	R
23	Student 23	T	T	T	T	R	R	R	R
24	Student 24	T	N T	T	T	R	R	R	R
25	Student 25	T	T	T	T	R	R	R	R
26	Student 26	T	N T	T	T	R	R	R	N R
27	Student 27	T	N T	T	T	R	R	R	R
28	Student 28	T	N T	T	T	R	R	R	R

Table 5.
Data Adapted For The Decision-Tree

No	Class	T_Discover Hidden Letter	T_Treasure Hunt	T_Toy Conquest	T_Freight Train	R_Discover Hidden Letter	R_Treasure Hunt	R_Toy Con-quest	R_Freight Train
1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	0	1	1	1	0
3	1	1	1	1	1	1	1	1	1
4	1	1	1	1	1	1	1	1	1
5	1	1	1	1	1	1	1	1	1
6	1	1	1	1	1	1	1	1	1
7	1	1	1	1	1	1	1	1	1
8	1	1	1	1	0	0	1	1	1
9	1	1	1	1	1	1	1	1	1
10	1	1	1	1	1	1	1	1	1
11	1	1	1	1	1	1	1	1	1
12	1	1	1	1	1	1	1	1	1
13	1	1	1	1	1	0	1	1	1
14	1	1	1	1	1	0	1	1	1
15	1	1	1	1	1	1	1	1	1
16	1	0	0	0	0	0	0	0	0
17	1	0	1	1	0	0	1	1	1
18	1	1	1	1	1	1	1	1	1
19	1	0	0	1	0	1	1	1	0
20	1	1	1	1	1	0	1	1	1
21	1	0	0	0	0	0	1	0	0
22	1	1	1	1	1	1	1	1	1
23	1	0	0	0	0	0	0	0	0
24	2	1	1	1	1	1	1	1	1
25	2	1	1	1	1	1	1	1	1
26	2	1	1	1	1	0	1	1	1
27	2	1	0	1	1	0	0	1	1
28	2	1	1	1	1	0	0	1	1
29	2	1	0	1	1	1	0	1	1
30	2	1	0	1	0	0	0	1	0
31	2	1	1	1	1	0	1	1	1
32	2	1	1	1	1	1	0	1	1
33	2	1	1	1	1	1	1	1	1
34	2	0	0	1	1	0	0	1	1
35	2	1	0	1	1	0	0	1	1
36	2	1	1	1	1	0	1	1	0
37	2	0	0	1	0	0	0	1	0
38	2	1	1	1	1	1	1	1	1
39	2	0	0	1	0	0	0	1	0
40	2	1	0	0	0	0	0	0	0
41	2	1	1	1	1	0	1	1	1
42	2	1	1	1	1	1	1	1	1
43	2	0	0	1	1	0	0	1	1
44	2	1	0	1	1	0	0	1	1
45	2	0	0	1	1	0	0	1	1
46	3	0	1	1	1	1	0	1	1
47	3	1	1	1	1	1	1	1	1
48	3	1	0	1	1	1	1	1	1
49	3	1	1	1	1	1	1	1	0
50	3	1	1	1	1	1	1	1	0
51	3	1	1	1	1	0	1	1	1
52	3	1	1	1	1	0	1	1	1
53	3	1	1	1	1	1	1	1	1
54	3	1	1	1	1	1	1	1	1
55	3	0	0	1	1	1	1	1	1
56	3	1	0	1	1	0	1	1	1

57	3	1	0	1	1	1	1	1	1
58	3	1	0	1	0	0	1	1	1
59	3	0	0	0	0	0	0	0	1
60	3	1	1	1	1	1	1	1	1
61	3	1	1	1	1	1	1	1	1
62	3	0	1	1	0	0	1	1	0
63	3	1	0	1	0	0	1	1	1
64	3	1	0	1	1	0	0	1	1
65	3	1	0	1	0	0	1	1	1
66	3	1	0	1	0	1	1	1	1
67	3	1	0	1	1	1	1	1	1
68	3	1	1	1	1	1	1	1	1
69	3	1	0	1	1	1	1	1	1
70	3	1	1	1	1	1	1	1	1
71	3	1	0	1	1	1	1	1	0
72	3	1	0	1	1	1	1	1	1
73	3	1	0	1	1	1	1	1	1