The Use of Tetris-Based Sequences for the Development of Mental Rotation and Spatial Skills in Students Aged 11 to 13

David Jiménez-Ruiz, Pascual D. Diago*, and Miguel Á. García-Moreno

Department de Didàctica de la Matemàtica, Universitat de València, València, Spain

Email: jiruizda@alumni.uv.es (D.J.R.), pascual.diago@uv.es (P.D.D.), miguel.garcia-moreno@uv.es (M.A.G.)

*Corresponding author

Manuscript received June 14, 2024; revised August 20, 2024; accepted September 30, 2024; published December 11, 2024

***Abstract*—Mental rotation and spatial skills are not innate abilities and therefore require development. These skills involve the ability to accurately perceive objects in space, manipulate them mentally, and recreate situations without direct sensory input. Physiological studies suggest that the optimal period for enhancing spatial skills is between the ages of 11 and 13, when brain stimulation is heightened during the execution of concrete and formal operations. This quasi-experimental study aims to use Tetris-based sequences, which utilize the dynamics of the classic Tetris video game, to facilitate the acquisition of spatial skills and mental rotation in a sample of 181 students aged 11 to 13. This study employs an innovative experimental setup based on instructional sequences utilizing Tetris-based sequences. In particular, Tetris-based sequences were employed in both paper-and-pencil and digital formats, with the control group using the former and the experimental group using the latter. Through quantitative methods, we found that Tetris-based sequences significantly enhance spatial abilities in both groups. However, the use of the digital version of the Tetris-based sequences was associated with a significant decrease in mental rotation performance.**

***Keywords*—Tetris-based sequences, mental rotation, spatial skills, game-based learning, visual-spatial abilities**

I. Introduction

While various technological tools within the student's environment, such as video games, have been recognized for their potential to enhance the acquisition of certain knowledge and curricular content, there remains a significant research gap in understanding the specific mechanisms through which these tools influence cognitive development, particularly in the realm of spatial abilities and mental rotation. Although the classic video game Tetris has been extensively studied, most existing research has focused on its general impact on cognitive skills, with limited attention given to its potential as a targeted educational tool for developing specific spatial skills in adolescents [1, 2].

The empirical literature on spatial reasoning often categorizes mental rotation and spatial skills as critical components of mathematical knowledge, especially within the domain of geometry [3, 4]. However, there is a scarcity of research that directly investigates how Tetris-based mechanics can be systematically applied to educational contexts to foster these abilities in students aged 11 to 13 [1, 2]. Moreover, the differential effects of physical (tangible) versus digital environments on the development of these skills remain largely unexplored.

This study addresses these empirical gaps by analyzing the relationship between the use of Tetris game mechanics and the acquisition of spatial abilities and mental rotation in early adolescents. We specifically examine the impact of Tetris-based sequences, designed to engage users in tasks requiring the rotation of geometric bodies, within both physical and digital environments. By doing so, this research contributes to a more nuanced understanding of how game-based learning can be effectively harnessed to enhance spatial cognition in educational settings.

In this context, this study aims to answer the following research questions:

- [RQ1] Does the use of Tetris-based sequences influence the acquisition of mental rotation and spatial abilities in students aged 11 to 13 years?
- [RQ2] Are there differences in the acquisition of mental rotation and spatial abilities in students aged 11 to 13 years when using Tetris-based interventions, depending on the medium (digital—video game format or tangible—paper-and-pencil)?
- [RQ3] If differences are detected based on the type of medium (digital vs. tangible), are there further differences depending on the gender of the students?

II. Literature Review

A. On Spatial Abilities from Mathematical Research

Battista [4] describes geometry as "a complex network of concepts, reasoning methods, and representation systems that we use to conceptualize and analyze the spatial environment physically or mentally". This complexity leads educational research on the teaching and learning of geometry to approach the subject from diverse perspectives [5]. Specifically, in mathematics education research in geometry many authors have distinguished between the skills for the formal representation of the surrounding space (in mathematical terms) and the skills for visualizing, constructing, drawing, etc., physical aspects and relationships between objects. The former skills are related to geometric thinking per se, while the latter skills pertain to spatial thinking [4–6].

In this study, we will focus on skills inherent to spatial thinking, which encompasses the set of knowledge that allows us to evoke, examine, and reflect on spatial objects and images, as well as the relationships and transformations that can be established between them [6]. These spatial skills include different constructs, as mental rotation, visualization, spatial orientation, useful field of view, perceptual speed, visuospatial memory among others [7, 8]. Thus, in this study, we will focus on assessing spatial skills on one hand, and the ability of mental rotation, as a specific construct of these spatial skills, on the other.

doi: 10.18178/ijiet.2024.14.12.2197

The literature provides solid evidence that the acquisition of spatial skills by students is a reliable predictor of success in mathematical tasks across all educational stages [9–13]. The meta-analysis by Uttal [14] concluded that "training spatial thinking (i.e., spatial skills) is effective, durable, and transferable" (p. 365). Moreover, it has been demonstrated that these spatial skills can be improved through training, leading to enhanced mathematical performance (as observed, for example, by Cheng [15] in a sample of students aged 6 to 8 years). However, despite its evident importance, the development of spatial thinking has not yet received the attention it requires in school curricula, as indicated by Whiteley [16].

B. On Tetris Gameplay Dynamics

Tetris is a logic-based video game originally designed by Aleksei Pazhitnov in 1984. The objective of this well-known game is to connect geometric shapes, known as *tetrominoes*, which are composed of four identical squares connected orthogonally, to complete horizontal lines at the bottom of the screen. The pieces fall from the top of the screen, and the player can rotate them (0°, 90°, 180°, 270°) and move them during their descent. Each completed horizontal line disappears, allowing the pieces above to shift down by one position, thereby freeing up space for new pieces. Due to the great success of Tetris, many games (not just video games) have adopted similar gameplay dynamics over the past decades. These dynamics are primarily based on the use of spatial skills, particularly the mental rotation of objects in space. As expected, research has utilized the Tetris video game to explore the mastery of mental imagery, as well as visual and spatial aspects, improving mechanics and skills in visuospatial tasks [2, 17–20]. Specifically, using magnetic resonance imaging (MRI) techniques, Agren [19] identified the areas of the brain activated when exercising mental rotation exercises in a game of Tetris by employing mild MRI scans to measure brain activity.

Games that employ Tetris-based dynamics are characterized by two or three dimensions. Previous studies have shown that regular use of two-dimensional Tetris-like video games improves users' mental rotation skills. In contrast, regular use of two and three-dimensional Tetris-based video games significantly enhances users' spatial vision and orientation [20]. Furthermore, these skills can be further developed in games that use different 3D perspectives to complete levels [21].

C. Research on Mental Rotation

Mental rotation is the ability to mentally rotate spatial objects (either 2D or 3D) to visualize how they would appear from a different angle or perspective [22]. Mental rotation is one of the spatial skills where the largest performance difference between genders has been observed, favoring men [23, 24]. Various meta-analyses and long-term studies have reported a considerable effect size in the gender gap for skills related to mental rotation [23, 25, 26].

Furthermore, mental rotation has been frequently studied in connection with the STEM fields (Science, Technology, Engineering, and Mathematics). Some authors explain the performance gap in mental rotation between boys and girls in terms of STEM-related skills, which also tend to favor men [27, 28]. Specifically, Baenninger and Newcombe demonstrated that both men and women improve at similar rates in their mental rotation skills when engaging in spatial skill tasks [29]. However, they found a difference in the number of tasks that each gender was able to complete. Their study observed positive effects on mental rotation through training and repetition, regardless of gender. Nonetheless, it revealed that boys were predominantly motivated by a competitive drive to outperform one another, whereas girls were predominantly more interested in exploring and practicing different spatial skills. Regarding Tetris, despite the inherent relationship between mental rotation skills and the Tetris playing dynamics, "no formal cognitive task analysis of Tetris playing has been completed" [1].

In this quasi-experimental study, we present an investigation of the effect of Tetris-based dynamics on the acquisition of mental rotation and spatial skills, focusing on how students interact with Tetris-based teaching sequences and the influence of students' gender.

III. MATERIALS AND METHODS

A. Participants

A convenience sampling method was used in the study. The participants were 181 students aged 11 and 13 years from three different public schools. No students diagnosed with special educational needs were included, so no methodological adaptations were necessary.

B. Procedure

A quasi-experimental intervention was designed in which participants were divided into a control group and an experimental group. The experimental group used the digital version of the Tetris video game, while the control group utilized paper-and-pencil materials based on the dynamics of the Tetris game. In both groups, a pre-test was administered prior to the intervention and a post-test afterward to asses measures related to spatial ability and mental rotation (the instruments are described in the following subsection).

Since the students belonged to different schools were organized into natural groups within their respective classes, each entire class was assigned either to the experimental or control condition. This approach ensured that there were no differences in the students' perception of the various tools used by each group. As shown in Table 1, the experimental group comprised a total of 105 students (50.47% female and 49.53% male), while the control group consisted of 76 students (52.63% female and 47.37% male).

Table 1. Distribution of participants

School ID	Total	Natural classes	Group
CAM	50	A: 25 students	Experimental
		B: 25 students	Control
FOI	41	A: 20 students	Experimental
		B: 21 students	Control
SAN	90	A: 30 students	Experimental
		B: 30 students	Experimental
		C: 30 students	Control

The time allocated for the intervention was determined by the availability of the schools. In total, two sessions per school were conducted, spaced two days apart. Each session lasted 55 minutes. The pre-test and post-test were administered at the beginning of the first session and at the end of the second session, respectively.

Regarding the intervention sequence, the experimental group used the online version of the Tetris video game on tablets or Chromebooks provided by their schools. The version of the video game used (Fig. 1) allowed each student to individually select the difficulty level before starting the game. During the two intervention sessions, games were played for approximately 15 minutes each, interspersed with active breaks of about 5 minutes, during which recreational activities based on traditional games were proposed.

Fig. 1. Screenshots of the Tetris video game used in the experimental group.

For the control group, a custom paper-and-pencil material was designed to simulate the mechanics of a Tetris game in physical format. This material was based on the manipulative puzzle game "Pentomino", but in this case, the pieces were printed directly on the sheet of paper itself, with no physically movement possible. As shown in Fig. 2, participants started with a specific number of geometric shapes similar in style and design to those of Tetris and attempted to complete the as many columns as possible in the provided empty grid. To achieve this, each participant had to consider the various possibilities and test different solutions. Similar to the experimental group, tasks of this nature were conducted for approximately 15 minutes each, with 5-minute active breaks interspersed.

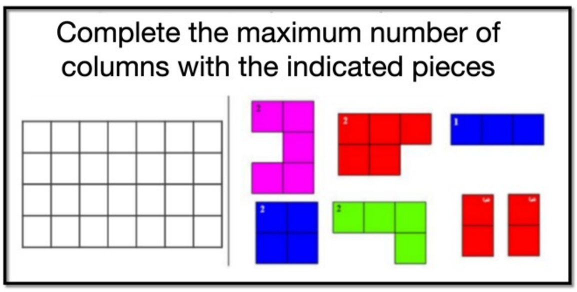

Fig. 2. Worksheets for the control group.

C. Data Collection and Analysis Methods

To assess the influence of using the Tetris-based sequences described earlier, a pre-test and post-test were administered to both the experimental and control groups. Since the study aims to measure the acquisition of spatial skills and mental rotation, the tests were constructed using validated and publicly accessible items commonly used in spatial skills acquisition research.

Specifically, our pre-test consisted of 30 items, along with an additional 30 isomorphic items for the post-test. For the measurement of the spatial skills, 14 items were chosen from the Spatial Reasoning Instrument (SRI) [30], which consists of multiple-choice questions with a single correct answer. The SRI is designed to assess spatial thinking abilities in children aged 11–13, with a particular focus on mental rotation, spatial orientation, and mental visualization.

To assess the mental rotation construct, 16 items were selected from the Thurstone Primary Mental Abilities questionnaire [31]. This questionnaire is part of a study conducted by the University of Chicago focusing on primary mental abilities in both children and older individuals.

The selection criterion for the items in the aforementioned questionnaires was their suitability for 12-year-old children. This selection was carried out through expert judgment, with a panel of three active school teachers who assessed the familiarity of the presented concepts for middle- to high-school students. The overall correlation coefficient (Cronbach's alpha) was 0.62 for the selected spatial-skill items and 0.57 for the selected mental rotation items, indicating acceptable reliability for the assessment of psychological constructs [32]. Fig. 3 shows some example items for each of the developed tests. The data collected from both tests were anonymized, including only a class identifier and a student identification number. Each correct item was scored as 1 and each incorrect item as 0. The total scores for each questionnaire were normalized to a 0-1 scale.

For the administration of the questionnaires, the selected items were adapted to be displayed on a digital whiteboard. Students were provided with a multiple-choice response sheet to mark their answers. For each item, the teacher read the statement aloud, allowing students to focus their attention on visualizing the object or figure. Items assessing spatial ability were displayed on the digital whiteboard for 30 seconds, while items assessing mental rotation were shown for 15 seconds. The administration of the post-test was conducted in exactly the same manner.

All statistical analyses were conducted using the R software, with a predetermined significance level of .05. Effect sizes were evaluated using appropriate measure. The normality of the data was assessed using the Shapiro-Wilk test. In cases where the assumption of normality was violated, the nonparametric Mann-Whitney or Wilcoxon tests were employed to compare the means of different or the same participants.

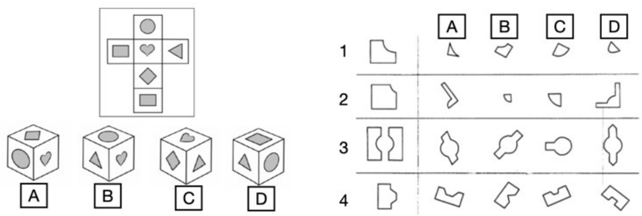

Fig. 3. Example of an item for assessing spatial skills (left) and four items for assessing mental rotation (right).

IV. Results

Tables 2 and 3 provide an overview of the results obtained from the analysis of pre-test and post-test scores for each group, disaggregated by gender. These data are also illustrated in the bar chart shown in Fig. 4 for explanatory purposes (MR refers to mental rotation scores and SA to spatial abilities scores).

It is important to note that the experimental and control groups did not show significant differences in the pre-tests for mental rotation ($W = 4015.5, p > 0.05$) or spatial abilities ($W = 3808, p > 0.05$). This indicated that both groups started from a comparable baseline level in terms of mental rotation and spatial abilities.

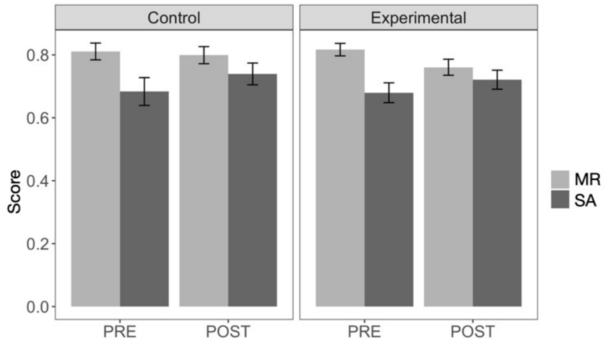

Fig. 4. Normalized scores for the pre-test and post-test.

In the following we explore the following hypotheses derived from the research questions in terms of hypothesis testing:

- The use of Tetris-based sequences significantly influences the acquisition of mental rotation and spatial abilities in students aged 11 to 13 years.
- There are significant differences in the acquisition of mental rotation and spatial abilities in students aged 11 to 13 years when using Tetris-based interventions, depending on the medium (digital—video game format or tangible—paper-and-pencil).
- If differences are detected based on the type of medium (digital vs. tangible), there are further significant differences in the acquisition of mental rotation and spatial abilities depending on the gender of the students.

A. Results on Mental Rotation

Regarding mental rotation, we observed that both the control group and the experimental group experienced a decline in their scores following the Tetris-based task sequences. Specifically, students in the control group (paper-and-pencil) had a mean score of 0.81 on the pre-test and 0.80 in the post-test. This difference in mental rotation skills was found to be non-significant, $V = 1010, p = 0.641$.

The students of the experimental group obtained an average score of 0.82 on the pre-test, which decreased to 0.76 in the post-test after using the Tetris video game in the intervention. This decline in their mental rotation skills was statistically significant, $V = 2992.5$, $p < 0.05$, with a medium effect size, $r = 0.34$.

Table 2. Results for mental rotation

	n	pre-test		post-test	
		mean	sd	mean	sd
Control	76	0.81	0.12	0.80	0.12
Males	36	0.84	0.09	0.79	0.10
Females	40	0.76	0.12	0.81	0.13
Experimental	107	0.82	0.10	0.76	0.13
Males	53	0.80	0.09	0.74	0.14
Females	54	0.83	0.11	0.79	0.12

B. Results on Spatial Abilities

Regarding spatial skills, students in the control group obtained a mean score of 0.68 on the pre-test, which increased to 0.74 following the intervention with paper-and-pencil materials. This difference in spatial skills was found to be significant ($V = 849$, $p < 0.05$), although the effect size was small, $r = 0.25$.

The results for the experimental group showed that the use of Tetris video game led to an increase in the mean score from 0.68 on the pre-test to a 0.72 on the post-test. Although the improvement was smaller compared to the control group, this increase was statistically significant ($V = 1549.5$, $p < 0.05$), with a small effect size, $r = 0.21$.

Table 3. Results for spatial abilities

	n	pre-test		post-test	
		mean	sd	mean	sd
Control	76	0.68	0.19	0.74	0.15
Males	36	0.74	0.18	0.77	0.15
Females	40	0.63	0.18	0.72	0.14
Experimental	107	0.68	0.16	0.72	0.16
Males	53	0.68	0.18	0.71	0.18
Females	54	0.68	0.14	074	0.14

C. Analysis of the Results by Gender

In this section, we will disaggregate the results for mental rotation and spatial skills by gender.

1) Mental rotation by gender

Regarding mental rotation, male students in the control group (paper-and-pencil) obtained a mean score of 0.85 before the intervention. Their post-test score significantly declined to a mean of 0.79 after the intervention ($V = 317$, $p < 0.05$), with a medium effect size, $r = 0.45$. For male students in the experimental group, the use of the Tetris video game caused their initial mean score of 0.80 on the pre-test to significantly decrease to a mean of 0.74 after the intervention, with a medium effect size ($V = 833$, $p < 0.05$, $r = 0.39$).

Female participants in the paper-and-pencil group improved their mean score from 0.76 on the pre-test to 0.81 on the post-test, but this difference was not significant ($V = 236$, $p = 0.3$). In contrast, female participants using the Tetris video game experienced a significant decline in their mental rotation skills, with their mean score decreasing from 0.83 on the pre-test to 0.79 on the post-test, accompanied by a medium effect size ($V = 676$, $p < 0.05$, $r = 0.29$).

2) Spatial abilities by gender

The results obtained from the paper-and-pencil group, separated by gender, indicate an improvement in spatial skills among male participants, with their mean score increasing from 0.74 on the pre-test to 0.77 on the post-test, although this improvement was not significant ($V = 193$, $p = 0.4$). Similarly, male participants who used the Tetris video game showed an increase in their spatial skills, with their mean score rising from 0.68 on the pre-test to 0.71 on the post-test, though this difference was also not significant ($V = 389$, $p = 0.3$).

On the other hand, regarding female participants, the results showed how girls in the control group significantly improved their spatial skills, with their mean score increasing from 0.63 before the Tetris-based intervention to 0.72 afterward, demonstrating a medium effect size ($V = 288$, $p <$

0.05, $r = 0.36$). Similarly, female students who used the Tetris video game also showed significant improvement, with their mean score rising from 0.68 on the pre-test to 0.74 on the post-test, accompanied by a medium effect size ($V = 388$, $p < .05$, $r = 0.28$).

To conclude this section, Table 4 summarizes the gains or losses in mean scores for mental rotation and spatial skills by group and gender, along with the significance of the detected differences.

Table 4. Summary of mean differences between pre-test and post-test

	Mental rotation	**Spatial abilities**
Control	decrease	increase (sig.)
Males	decrease (sig.)	increase
Females	increase	increase (sig.)
Experimental	decrease (sig.)	increase (sig.)
Males	decrease (sig.)	increase
Females	decrease (sig.)	increase (sig.)

V. Discussion

In this section, we discuss the differences observed between the pre-test and post-test, which were supported by the comparable initial levels of both groups in mental rotation and spatial abilities, as indicated by the pre-test.

The results presented in the previous section indicate that, with regard to mental rotation, both the control group and the experimental group experienced a decline in scores following their respective Tetris-based sequences. Specifically, the experimental group showed a significant decrease in their mental rotation abilities due to the use of the Tetris video game. In contrast, the results differed when analyzing spatial skills. Both groups improved their spatial abilities after the intervention, with the improvement in the experimental group being significant. This spatial ability improvement is aligned with the positive effects using the Tetris-based dynamics in preadolescents [20].

The analysis of results by gender revealed two noteworthy findings: i) with respect to mental rotation, all students experienced a significant decline except for the control group of girls, who showed a slightly improvement (though not significantly); and ii) regarding spatial skills, all groups demonstrated improvement, but significantly progress was observed only among girls in both the control and the experimental groups. Since this intervention is not directly related to STEM proposals, we cannot speculate on any potential relationship with the bias described in the literature review in favor of men [27, 28]. In this context, our results are more aligned with the assertion of Baenninger and Newcombe [29], who reported that both boys and girls performed similarly on tasks involving spatial abilities.

Regarding the medium employed during the intervention, the results indicate that the Tetris-based sequence used in the control group with pen and paper led to an enhancement of spatial skills in all cases, with this improvement being significant for girls. These tangible and manipulable materials may have enhanced interest in exploring and practicing various spatial skills [29], in contrast to the less flexible approach provided by the digital format. Conversely, the use of the Tetris video game in the experimental group had a negative (and significant) effect on the mental rotation abilities of both genders. These findings align with previous studies on the potential of video games in mathematics education, which emphasize that video games have not been conclusively proven to be an entirely effective tool for learning mathematics [33].

VI. Conclusions

One of the main limitations of the experimental design was the limited time available for conducting the intervention in schools (only 2 hours). However, other studies examining spatial abilities have also utilized brief interventions (approximately 2 hours), which have produced robust results [34, 35]. Furthermore, the time allocated to spatial content during the academic year is typically limitated to no more than 2 h.

In conclusion, we address the research questions posed and provide reasoned answers based on the results obtained. Concerning RQ1, we can confirm that using sequences based on Tetris-dynamics did influence the mental rotation and spatial abilities of students aged 11 to 13. This influence was both positive and negative: it enhanced spatial abilities across all participants but also diminished mental rotation abilities.

In addressing RQ2, we observed that the medium through which tasks based on Tetris game dynamics are presented significantly impacts mental rotation. Although this aspect was not extensively investigated in this study, a plausible explanation could be that the Tetris video game (used by the experimental group) does not require active mental rotation of the pieces to complete the task. This is because, in the digital setup, a simple action (pressing a key) allows the figure to be rotated in the desired direction automatically, so the student does not need to visualize the result of the rotation. In contrast, the control group used static geometric figures, requiring participants to imagine the final position of each figure to complete the task.

Finally, addressing RQ3, the gender analysis of the differences in mental rotation and spatial abilities based on the medium revealed a significant improvement in spatial abilities among female participants (regardless of whether the medium was physical or digital) and a significant decline in mental rotation abilities among male participants.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Conceptualization, D.J.R and P.D.D.; methodology, D.J.R and P.D.D.; data curation, D.J.R., P.D.D. and M.A.G.; writing---original draft preparation, D.J.R. and P.D.D.; writing---review and editing, D.J.R, P.D.D. and M.A.G.; supervision, P.D.D.; all authors had approved the final version.

Funding

This research was supported by Conselleria d'Innovació, Universitats, Ciència i Societat Digital de la Generalitat Valenciana through grants number GV/2019/146 and AICO/2021/019.

References

[1] C. Pilegard and R. E. Mayer, "Game over for Tetris as a platform for cognitive skill training," *Contemporary Educational Psychology*, vol. 54, pp. 29–41, 2018. https://doi.org/10.1016/j.cedpsych.2018.04.003

[2] C. V. Károlyi, "From Tesla to Tetris: Mental rotation, vocation, and gifted education," *Roeper Review*, vol. 35, no. 4, pp. 231–240, 2013. https://doi.org/10.1080/02783193.2013.829547

[3] H. B. Yilmaz, "On the development and measurement of spatial ability," *International Electronic Journal of Elementary Education*, vol. 1, no. 2, pp. 83–96, 2019.

[4] M. T. Battista, "The development of geometric and spatial thinking," in *Second Handbook of research on Mathematics Teaching and Learning*, F. K. Lester (Ed.), pp. 843–908, National Council of Teachers of Mathematics, 2007.

[5] Á. Gutiérrez, "Enseñanza y aprendizaje de la geometría," *Investigación en educación matemática XIV*, pp. 17–19, Lérida: SEIEM, 2010.

[6] D. H. Clements, and M. T. Battista, "Geometry and spatial reasoning," *Handbook of Research on Mathematics Teaching and Learning*, pp. 420–464, National Council of Teachers of Mathematics, 1992.

[7] Z. Usiskin, "Resolving the continuing dilemmas in school geometry," *Learning and Teaching Geometry, k-12*, pp. 17–31, Reston, VA: National Council of Teachers of Mathematics, 1987.

[8] W. Whiteley, N. Sinclair, and B. Davis, "What is spatial reasoning?" *Spatial Reasoning in the Early Years*, pp. 3–14, New York, NY: Routledge, 2015.

[9] K. Jones and M. Tzekaki, "Research on the teaching and learning of geometry," *The Second Handbook of Research on the Psychology of Mathematics Education: The Journey Continues*, pp. 109–149, Rotterdam: Sense Publishers, 2016. doi: 10.1007/978-94-6300-561-6_4

[10] K. A. Gilligan, E. Flouri, and E. K. Farran, "The contribution of spatial ability to mathematics achievement in middle childhood," *Journal of Experimental Child Psychology*, vol. 163, pp. 107–125, 2017. doi: 10.1016/j.jecp.2017.04.016

[11] M. Pittalis and C. Christou, "Types of reasoning in 3D geometry thinking and their relation with spatial ability," *Educational Studies in Mathematics*, vol. 75, no. 2, pp. 191–212, 2010. doi: 10.1007/s10649-010-9251-8

[12] D. L. Shea, D. Lubinski, and C. P. Benbow, "Importance of assessing spatial ability in intellectually talented young adolescents: A 20-year longitudinal study," *Journal of Educational Psychology*, vol. 93, no. 3, pp. 604–614, 2001. doi: 10.1037/0022-0663.93.3.604

[13] J. Wai, D. Lubinski, and C. P. Benbow, "Spatial ability for STEM domains: Aligning over 50 years of cumulative psychological knowledge solidifies its importance," *Journal of Educational Psychology*, vol. 101, no. 4, pp. 817–835, 2009. doi: 10.1037/a0016127

[14] D. H. Uttal, N. G. Meadow, E. Tipton, L. L. Hand, A. R. Alden, C. Warren, and N. S. Newcombe, "The malleability of spatial skills: A meta-analysis of training studies," *Psychological Bulletin*, vol. 139, no. 2, pp. 352–402, 2013. doi: 10.1037/a0028446

[15] Y. L. Cheng and K. S. Mix, "Spatial training improves children's mathematics ability," *Journal of Cognition and Development*, vol. 15, no. 1, pp. 2–11, 2014. doi: 10.1080/15248372.2012.725186

[16] W. Whiteley, N. Sinclair, and B. Davis, "What is spatial reasoning?" *Spatial reasoning in the Early Years*, pp. 3–14, New York, NY: Routledge, 2015.

[17] E. A. Holmes, A. Ghaderi, C. J. Harmer *et al*., "The Lancet Psychiatry commission on psychological treatments research in tomorrow's science," *The Lancet Psychiatry*, vol. 5, no. 3, pp. 237–286, 2018. doi: 10.1016/S2215-0366(17)30513-8

[18] L. Iyadurai, S. E. Blackwell, R. Meiser-Stedman *et al*., "Preventing intrusive memories after trauma via a brief intervention involving Tetris computer game play in the emergency department: A proof-of-concept randomized controlled trial," *Molecular Psychiatry*, vol. 23, no. 3, pp. 674–682, 2018. doi: 10.1038/mp.2017.23

[19] T. Agren, J. M. Hoppe, L. Singh, E. A. Holmes, and J. Rosén, "The neural basis of Tetris gameplay: Implicating the role of visuospatial processing," *Current Psychology*, 2021. doi: 10.1007/s12144-021-02081-z

[20] L. Milani, S. Grumi, and P. D. Blasio, "Positive effects of videogame use on visuospatial competencies: The impact of visualization style in preadolescents and adolescents," *Frontiers in Psychology*, vol. 10, 2019. doi: 10.3389/fpsyg.2019.01226

[21] L. A. Gordo, "Jugando con el espacio y el tiempo," *SUMA: Revista sobre Enseñanza y Aprendizaje de las Matemáticas*, vol. 80, pp. 79–85, 2015.

[22] R. N. Shepard and J. Metzler, "Mental rotation of three-dimensional objects," *Science*, vol. 171, no. 3972, pp. 701–703, 1971. doi: https://doi.org/10.1126/science.171.3972.701

[23] C. Geiser, W. Lehmann, and M. Eid, "A note on sex differences in mental rotation in different age groups," *Intelligence*, vol. 36, no. 6, pp. 556–563, 2008. doi: 10.1016/j.intell.2007.12.003

[24] S. P. Johnson and D. S. Moore, "Spatial thinking in infancy: Origins and development of mental rotation between 3 and 10 months of age," *Cognitive Research: Principles and Implications*, vol. 5, no. 1, 2020. https://doi.org/10.1186/s41235-020-00212-x

[25] D. Voyer, S. Voyer, and M. P. Bryden, "Magnitude of sex differences in spatial abilities: A meta-analysis and consideration of critical variables," *Psychological Bulletin*, vol. 117, no. 2, pp. 250–270, 1995. doi: 10.1037/0033-2909.117.2.250

[26] N. S. Newcombe and M. Stieff, "Six myths about spatial thinking," *International Journal of Science Education*, vol. 34, no. 6, pp. 955–971, 2012. doi: 10.1080/09500693.2011.588728

[27] S. J. Ceci, W. M. Williams, and S. M. Barnett, "Women's underrepresentation in science: Sociocultural and biological considerations," *Psychological Bulletin*, vol. 135, no. 2, pp. 218–261, 2009. doi: 10.1037/a0014412

[28] J. Wai, D. Lubinski, and C. P. Benbow, "Spatial ability for STEM domains: Aligning over 50 years of cumulative psychological knowledge solidifies its importance," *Journal of Educational Psychology*, vol. 101, no. 4, pp. 817–835, 2009. doi: 10.1037/a0016127

[29] M. Baenninger and N. Newcombe, "The role of experience in spatial test performance: A meta-analysis," *Sex Roles*, vol. 20, no. 5, pp. 327–344, 1989. doi: 10.1007/BF00287729

[30] A. Ramful, T. Lowrie, and T. Logan, "Measurement of spatial ability: Construction and validation of the spatial reasoning instrument for middle school students," *Journal of Psychoeducational Assessment*, vol. 35, pp. 709–727, 2016.

[31] L. L. Thurstone, *Primary Mental Abilities*, Chicago: University of Chicago Press, 1938.

[32] J. M. Cortina, "What is coefficient alpha? An examination of theory and applications," *Journal of Applied Psychology*, vol. 78, no. 1, pp. 98–104, 1993.

[33] J. A. González-Calero and D. Arnau, "Game over or continue? Los videojuegos en la enseñanza de las matemáticas," in R. Cózar and M. del V. D. Moya (Eds.), *Entornos humanos digitalizados: experiencias TIC en escenarios educativos*, pp. 17–34, Síntesis, 2017.

[34] P. D. Diago, J. A. González-Calero, and D. F. Yáñez, "Exploring the development of mental rotation and computational skills in elementary students through educational robotics," *International Journal of Child-Computer Interaction*, vol. 32, 100388, 2022. https://doi.org/10.1016/j.ijcci.2021.100388

[35] J. A. González-Calero, R. Cózar, R. Villena, and J. M. Merino, "The development of mental rotation abilities through robotics-based instruction: An experience mediated by gender," *British Journal of Educational Technology*, vol. 50, pp. 3198–3213, 2019. https://doi.org/10.1111/bjet.12726