Revista Iberoamericana para la Investigación y el Desarrollo Educativo
ISSN 2007 - 7467

https://doi.org/10.23913/ride.v16i31.2716

Artículos científicos

Development of Human Talent in the classroom: Meaningful Learning through Metacognitive Strategies and Game-based activities

Desarrollo del Talento Humano en el aula: Aprendizaje Significativo a través de Estrategias Metacognitivas y Actividades Lúdicas

Desenvolvimento do Talento Humano na Sala de Aula: Aprendizagem Significativa por meio de Estratégias Metacognitivas e Atividades Lúdicas

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Resumen

Esta investigación tuvo por objetivo desarrollar el talento humano en el aula y establecer el grado de efectividad de la estrategia metacognitiva CRIME —acrónimo en inglés de *Carefully Read, Recall strategies, Implement, Monitor, Evaluate* (leer cuidadosamente, recordar estrategias, implementar, monitorear y evaluar)— frente al uso de actividades lúdicas para promover aprendizajes significativos en matemáticas. Metodológicamente, se implementaron talleres de resolución de problemas estadísticos en sexto grado de educación básica (una hora diaria durante ocho días hábiles consecutivos). Se utilizó un método mixto con diseño cuasiexperimental embebido (pretest, postest y seguimiento), con apoyo cualitativo mediante entrevistas antes, durante y después de la intervención. Participaron 40 estudiantes: 21 en el Grupo 1 (actividades lúdicas) y 19 en el Grupo 2 (estrategia metacognitiva). Los resultados muestran diferencias significativas entre pretest–postest y pretest–seguimiento en el Grupo 2; además, el análisis postest–seguimiento evidencia mantenimiento del aprendizaje con la estrategia metacognitiva, lo que indica aprendizaje significativo. La efectividad aumentó 5,5 % en el Grupo 1 y 13,6 % en el Grupo 2. Se concluye que la estrategia metacognitiva supera a las actividades lúdicas para el logro de aprendizajes significativos en matemáticas en estudiantes de sexto grado de educación básica.

Palabras clave: talento humano; aprendizaje significativo; estrategia metacognitiva (CRIME); actividades lúdicas; resolución de problemas estadísticos; educación básica.

Abstract

This study aimed to develop students’ human talent in the classroom by evaluating the effectiveness of the CRIME metacognitive strategy—Carefully Read, Recall strategies, Implement, Monitor, Evaluate—compared with game-based activities to promote meaningful learning in mathematics. Methodologically, the strategies were implemented through workshops focused on statistical problem-solving in sixth-grade elementary education (one hour per day for eight consecutive school days). It was used an embedded mixed-methods quasi-experimental design (pretest, posttest, and follow-up), with qualitative interviews conducted before, during, and after the intervention. Forty students participated: 21 in Group 1 (game-based activities) and 19 in Group 2 (metacognitive strategy). Results showed significant differences for pretest–posttest and pretest–follow-up in Group 2;

moreover, the posttest–follow-up comparison indicated that learning was maintained over time with the metacognitive strategy, evidencing meaningful learning. Effectiveness increased by 5.5% in Group 1 and by 13.6% in Group 2. It was concluded that the metacognitive strategy is more effective than game-based activities for fostering meaningful learning in elementary mathematics.

Keywords: human talent, meaningful learning, metacognitive strategy (CRIME), game-based activities, statistical problem solving, elementary school.

Resumo

Esta pesquisa teve como objetivo desenvolver o talento humano em sala de aula e estabelecer a eficácia da estratégia metacognitiva CRIME — um acrônimo para Ler com Atenção, Recordar Estratégias, Implementar, Monitorar e Avaliar — em comparação ao uso de atividades lúdicas para promover a aprendizagem significativa em matemática. Metodologicamente, foram implementadas oficinas de resolução de problemas estatísticos no sexto ano do ensino fundamental (uma hora diária durante oito dias letivos consecutivos). Utilizou-se uma abordagem de métodos mistos com um delineamento quase-experimental incorporado (pré-teste, pós-teste e acompanhamento), com suporte qualitativo por meio de entrevistas antes, durante e após a intervenção. Quarenta alunos participaram: 21 no Grupo 1 (atividades lúdicas) e 19 no Grupo 2 (estratégia metacognitiva). Os resultados mostram diferenças significativas entre o pré-teste e o pós-teste, bem como entre o pré-teste e o acompanhamento no Grupo 2; além disso, a análise do pós-teste e do acompanhamento demonstra que a aprendizagem foi mantida com a estratégia metacognitiva, indicando aprendizagem significativa. A eficácia aumentou 5,5% no Grupo 1 e 13,6% no Grupo 2. Conclui-se que a estratégia metacognitiva é superior às atividades lúdicas para alcançar uma aprendizagem significativa em matemática entre alunos do sexto ano do ensino fundamental.

Palavras-chave: talento humano; aprendizagem significativa; estratégia metacognitiva (CRIME); atividades lúdicas; resolução de problemas estatísticos; ensino fundamental.

Fecha Recepción: Marzo 2025 **Fecha Aceptación:** Noviembre 2025

Introduction

Throughout history, education has been the subject of study in various fields such as philosophy, sociology, psychology, pedagogy, among others. The pursuit of improvement in human talent development to increase academic achievement has led to the exploration of diverse perspectives on teaching and learning worldwide. However, Mexico's performance in basic education has been low in recent years, particularly in mathematics assessments.

In the 2022 edition of the Programme for International Student Assessment (PISA), Mexico had the worst results in science and ranked as the third-worst country in mathematics and reading comprehension. The Mexican Institute for Competitiveness (Instituto Mexicano de la Competitividad [IMCO], 2023, para. 5) also reports that "two out of every three students in Mexico do not reach the basic level of learning in mathematics".

The importance of every individual developing basic mathematical competencies lies in the continuous need to solve problems that arise in daily life, which require logical and orderly thinking to be solved effectively. Additionally, these skills enhance scientific development and enable the acquisition of more complex knowledge (Montes, 2024). Moreover, these competencies are part of the technical skills that future human talent will use at work (Oviedo & González, 2016).

The 2022 PISA test placed Mexico in 35th place out of 37 members of the Organization for Economic Co-operation and Development (OECD) regarding performance in mathematical performance, 71 points below the average, with the lowest scores alongside Chile, Costa Rica, and Colombia (OECD, 2023). In 2012, 55% of the students evaluated scored below level two in mathematics; by 2022, this percentage increased to 66%.

Considering that more than half of the basic education student population in Mexico did not and still do not have the necessary competencies to perform adequately at their grade level (OECD, 2023; OECD, 2016), the possibility of addressing this issue from elementary school was analyzed by the research group. The intention was to understand the importance of communicating, perceiving, and translating the world through the mathematical language present in everyone's life, including performance in the workplace.

Given the above, this research aimed to establish the effectiveness in generating meaningful learning through the metacognitive strategy CRIME (Carefully read, Recall strategies, Implement, Monitor, Evaluate) compared to the use of game-based activities in the classroom, focusing on statistical problems or primary school students in the sixth grade.

Meaningful Learning of Mathematics in Primary Education

Given the challenge Mexico faces in human talent development in the classroom, particularly in mathematics, various types of learning were analyzed from the perspective of cognitive psychology, such as meaningful learning, receptive learning, rote learning, discovery learning, among others. The search for understanding beyond memorization, the retention of learning over time, and the ability to transfer knowledge to diverse scenarios led to meaningful learning (Baque & Portilla, 2021).

Since learning is a subjective, individual, and idiosyncratic process in which each person creates their own path, it is important to focus specifically on the students' mental processes. Ausubel's (1963) theory of meaningful learning delved into how knowledge is acquired through these processes.

Ausubel sought to answer the questions of how we learn and why we forget what we learn, proposing the theory of meaningful learning, which allows for the acquisition and organization of knowledge in the cognitive structure in a not by rote and in a non-arbitrary manner (Moreira, 2000). According to this theory, when a student creates new knowledge through their cognitive processes to solve a mathematical problem, they are learning meaningfully (Cabanes & Colunga, 2017; Mayer, 2002).

Novak (2013) continued Ausubel's work on meaningful learning. Both gave it their own approach and made significant contributions, paving the way for other researchers to address the topic. Among the findings, positive results in mathematics through various strategies in generating meaningful learning stand out (Altamirano & Mera, 2023; Hernández et al., 2023; Suárez, 2018; Apino & Retnawati, 2017; Septriyana et al., 2018; Handayaningrum, 2016; Starcic et al., 2012).

Regarding this cognitive perspective, Barrios (2021) and Pintrich et al. (1993) found that focusing exclusively on cognitive learning outcomes while disregarding students' emotional factors represents an incomplete approach to education. The authors claim this approach fails to capture the complexity of classroom dynamics, underscoring the need for a more holistic and inclusive educational model.

On the other hand, Llanga et al. (2019) and Sinatra & Mason (2013) recognized the importance of affective factors in learning, indicating that motivation, goals, beliefs about what is possible, as well as emotions such as stress and anxiety could either benefit or hinder learning, depending on each person's socioemotional development.

This research focuses on analyzing two instructional strategies aimed at solving statistical problems to generate meaningful learning, with the intention of finding the most effective strategy for acquiring mathematical skills that enable primary school students to achieve effective performance and apply this learning to different scenarios in daily and professional life.

After reflecting on existing strategies for statistical problem-solving, the metacognitive strategy CRIME and game-based activities were selected as the most suitable for teaching mathematics in basic education, specifically in the upper grades of primary school. The decision was based on the fact that sixth-grade students require creative and practical strategies to situate learning in real-world contexts to learn meaningfully.

The CRIME strategy was specifically designed for solving mathematical problems (Teong, 2003). It involves carefully read the problem, recalling possible strategies to solve it, implementing the selected strategy, monitoring its effectiveness, and evaluating whether the expected result is achieved. Additionally, in this last step, it considers whether a change of strategy is necessary.

Generating Learning Through Metacognition

Metacognition is the "knowledge one has concerning one's own cognitive processes or anything related to them, such as the properties of information or data relevant to learning" (Flavell, 1976, p. 232). This knowledge of one's own cognitive processes is available for analysis, application, evaluation, and improvement whenever a specific task is performed.

Metacognitive strategies, used to enhance learning or evaluate one's own knowledge, also generate new experiences that can be invoked in the future (Flavell, 1979). Thus, the student can monitor how they solve a mathematical problem, analyze the strategy to determine if it is appropriate, if the correct result was achieved, or if a change of strategy is necessary. It is also possible to transfer what is learned in this process to other scenarios.

In addition to Flavell (1979), others have investigated metacognition but focused on metacognitive skills. Since then, other researchers have delved into generating learning through metacognition (Barría et al., 2022; Desoete, 2007; Ozsoy & Ataman, 2009; Jacobse, 2012; Safari & Meskini, 2016; Zepeda et al., 2015; Asarzadeh & Sayedi, 2016; Athukorala et al., 2024), with positive results in the use of metacognitive tools in mathematics.

Novak (2013) created a university course in which he taught new ways of learning through metacognition. A 30% dropout rate was reported because participants expected a quick solution to memorize just enough to pass their courses. However, the results indicate that students who remained throughout the semester developed a sense of empowerment over their own learning and increased their meaningful learning.

These studies show the benefits of metacognition in learning mathematics, making it viable to analyze a specific metacognitive strategy to verify its effectiveness in generating meaningful learning in solving statistical problems for sixth-grade students. A key question, then, is whether the selected metacognitive strategy will be more or less effective than the use of game-based activities in the classroom for this same purpose.

Generating Learning Through Game-Based Activities

Game-based activities in education began with Froebel (1903), the pioneer of preschool education, for whom play symbolizes the free representation of the child through various activities, as long as they include established rules. The benefit of these activities is that they generate strength, determination, and pleasure in participants. However, for the student to learn and develop through play, it is necessary to guide the learner toward the desired goal. Froebel adds that this type of teaching aims to make children's lives enriching and happy.

In addition to Froebel, other theorists have addressed and applied teachings based on play, giving game-based activities recognition. Among these authors is Montessori (1912), who recognized the importance of game-based activities in her theory and included them in their teaching-learning strategies. For example, the Montessori method uses game-based materials with a specific learning intention, tailored to the students' age.

Other authors have delved into researching game-based activities in the classroom (Lanza et al., 2024; Candela & Benavides, 2020; Heidari-Shahreza, 2024; Keskitalo et al., 2011; Fiorella et al., 2012; Hakkarainen et al., 2009; Güneş & Genç , 2021; Sawyer, 2017). The findings on fostering meaningful learning among students across various educational levels have shown positive outcomes. These studies have employed diverse strategies, including the use of board games and digital games.

Similarly, Plutin-Pacheco and García-López (2016) designed didactic games, both board- and computer-based games, for teaching chemistry in secondary school. In this case, the results showed that school averages after using the games were not significantly higher than those of the previous course. However, it was observed that students showed greater acceptance of the subject after the intervention.

Through these studies, the relevance of using game-based activities to achieve meaningful learning in mathematics is evident. This led to the design of a study to compare the efficacy of both metacognitive and game-based strategies in promoting successful classroom activities that contribute to achieving the mathematics learning objectives for sixth grade. To achieve this goal, it was necessary to determine which of these strategies yields a higher effectiveness rate.

Method

A quantitative design was used, consisting of a quasi-experiment with pretest, posttest, and follow-up. To avoid the ethical issue of demoralization and dropout in a no-treatment control group, each sixth-grade group received a workshop with a different strategy. Group 1 focused on the use of game-based activities, while Group 2 focused on the metacognitive strategy CRIME.

The method was designed to address the research objective, so the design aimed to establish the impact of game-based activities and metacognitive strategies on generating meaningful learning in statistical problem-solving among sixth-grade students.

Sample and Context

A bilingual primary school with a single morning shift was selected. According to the Mexican Association of Market and Opinion Intelligence Agencies (Asociación Mexicana de Agencias de Inteligencia de Mercado y Opinión [AMAI], 2018), both the students and the school, based on the geographical area, belong to a medium-high to medium SES (C+ and C, respectively).

The inclusion criteria for participants were: being enrolled as a sixth-grade student in the selected school, being between 9 and 12 years old, and having signed informed consent from their parents. No exclusion criteria were applied beyond not meeting these inclusion requirements.

The initial sample consisted of 40 participants. Group 1 consisted of 21 students, and Group 2 consisted of 19. However, due to attrition of three participants (who failed to complete the follow-up measurement), analyses included only participants with complete data at the three time points (n = 37), 20 from Group 1 and 17 from Group 2. Both groups had the same teacher, thus teacher effects were held constant.

Instruments

The test booklet for the pretest, posttest, and follow-up included a problem set. The instrument contained eight statistical problems with a total of 10 items, because two of them had two questions. The difficulty level was set for sixth-grade primary school. The items were selected from released problems by international organizations such as PISA, TIMSS, and Spain's national assessment. To categorize the problems, the PISA proficiency levels were used.

Procedure

The intervention was carried out through workshops, one-hour daily sessions over eight consecutive school days per group. The pretest was administered the week before the intervention began, the posttest the week after, and the follow-up one month later. The duration of the tests did not exceed 30 minutes, but no time pressure was applied to finish within a specific time. The instruments were administered half an hour before recess.

In the pretest, 39 out of 40 sixth-grade students participated (20 from Group 1 and 19 from Group 2), with one absence from Group 1. Attendance fluctuated in subsequent measurements. The student who had been absent returned for the postest, but two students from Group 2 were absent, resulting in a total of 38 participants (21 from Group 1 and 17 from Group 2). In the follow-up, Group 1 remained complete (21 students), and one of the two absent students from Group 2 returned, bringing the total to 39 participants (21 from Group 1 and 18 from Group 2). For ethical reasons, all students participated in the intervention process, but only the data from students present at all measurement points were analyzed. This resulted in three cases of attrition from the final dataset due to incomplete data across all three time points.

For the intervention, Group 1 received a workshop focused on solving statistical problems through game-based activities. Participants practiced statistical problem-solving and learned basic statistical concepts while participating in various games rotating across sessions, such as Jeopardy, Charades, Pictionary, and Memory.

Group 2 also focused on solving statistical problems but based on a metacognitive strategy. The same procedure was followed, but this group learned what CRIME means and how to use it. Metacognitive activities were used to learn and practice one letter of CRIME each day.

Analysis

Handling of missing data

There were three missing values on each of the three repeated measures across the time: pretest, posttest, and follow-up in group 2 (metacognitive strategy). The missing values in the pretest stage due to high variability, were imputed using the median of the existing values in the same stage. Subsequently, a regression analysis was performed between pretest and postest stages, and the missing values for postest stage were imputed using the values predicted by the regression equation. Similarly, a regression analysis was conducted between pretest and follow-up and the missing data in the follow-up stage were imputed using the values in the regression predictions.

Statistical technique

With the missing values handled in the dataset and in order to compare the effect of strategy type (Game-based activities vs. Metacognitive) over the meaningful learning in mathematics across the time, a within-between subjects design (Two-way mixed repeated measures ANOVA) analysis was applied. The between-subjects factor was the type of pedagogical intervention, which had two levels: (1) the metacognitive strategy CRIME and (2) game-based activities. The within-subjects factor was time, with three repeated measures across the time: pretest, posttest, and follow-up. The dependent variable was meaningful learning.

The statistical model was:

$$Y_{ij} = \mu + A_i + B_j + (A \times B)_{ij} + \epsilon_{ij}$$

Where:

A_i: *Pedagogical intervention*

B_j: *Time factor*

(AxB): *Interaction between Pedagogical intervention and time factor*

ϵ_{ij}: *error*

Verification of Assumptions

Prior to conducting the repeated measures ANOVA, the relevant assumptions were evaluated. Normality of the scores in each condition was assessed using the Shapiro-Wilk test. Homogeneity of variances for the factors of *time* and *pedagogical intervention* was evaluated with Levene's test. Sphericity for the *time* factor and the *time x pedagogical intervention* interaction was examined using Mauchly's test, as part of the ANOVA procedure. In cases where sphericity was violated ($p < 0.05$ in Mauchly's test), the Greenhouse-Geisser correction was applied to the degrees of freedom for the estimation of effects.

Post-Hoc Tests

After conducting the Repeated Measures ANOVA and identifying significant effects, post-hoc tests were performed to examine pairwise differences. Pairwise *t*-tests were employed to compare the differences between the levels of the factors time and pedagogical intervention, as well as their interaction. The Bonferroni correction was subsequently applied to the p-values for the pairwise comparisons related to the main effect of time, in order to control the Type I error rate. For the significant pairwise comparisons identified in the post-hoc analysis, effect sizes were calculated using Hedges' *g* to quantify the magnitude of the differences between the means.

Analysis

To assess the progress of participants throughout the quasi-experiment, paired-samples t-test (dependent samples) was applied to compare the average performance in the stages: pretest, posttest, and follow-up, all with a confidence level of 95%. On the other hand, to compare both strategies (metacognitive and game-based), the average performance of each group in the three stages was evaluated using a Student's T-test, also at a 95% confidence level.

Results

Pretest

A descriptive analysis of both groups combined revealed a general mean of 5.11 (SD = 2.10). The mode achieved by both groups was five, with 29.5%. Only 2.5% of the participants achieved the highest number of correct items, which was nine for the pretest. In contrast, 11% of the students answered only one out of 10 items correctly.

Group 1 had a mean of 5.75 (SD = 2.14), while Group 2 had a mean of 4.35 (SD = 1.83). The first group's performance ranged from one to nine correct items out of 10. In the second group, the results ranged from two to seven out of 10. The mode for Group 1 was seven, and for Group 2, it was five. In Group 1, 45% did not answer more than half of the booklet correctly. In Group 2, 76% did not achieve a performance level higher than five correct items.

Posttest

In the posttest, Group 1 achieved a mean of 6.30 (SD = 1.78), and Group 2 achieved a mean of 5.72 (SD = 1.99). On average, participants' performance increased 5.5% in Group 1 and 13.6% in Group 2 between the pretest and posttest. In terms of the number of correct items, Group 1 ranged from two to nine out of 10 items, while Group 2 ranged from two to 10 correct items.

Follow-up

In this final application, the mean for Group 1 was 5.88 (SD = 1.32), and for Group 2, it was 5.59 (SD = 1.69). The difference between the posttest and follow-up is a 5.0% decrease in performance for Group 1 and 1.2% decrease for Group 2. However, the decrease was only significant for those who worked with game-based activities. Figures 1 and 2 show the performance of Groups 1 and 2, respectively, in more detail regarding the number of correct items obtained.

Comparison Between Stages

The results of the two-way mixed repeated measures ANOVA are shown in Table 1.

Table 1. Two-way mixed repeated measures ANOVA results

Variation Source	SS	dof1	dof2	MS	F	p-unc	p-GG-corr	ng2	eps
A	17.82	2.00	38.00	8.91	18.96	0.00	0.00	0.05	0.89
B	13.33	1.00	19.00	13.33	2.09	0.16	0.16	0.04	1.00
AB	6.82	2.00	38.00	3.41	6.02	0.01	0.01	0.02	0.89

Factor A = Pedagogical intervention; Factor B = Time Factor, AB = Factor Interaction Effect

The analysis revealed a statistically significant main effect of time, $F_{(2)} = 18.96$, $p = < 0.05$, this result indicates that mean scores differed significantly across the three assessment points (pretest, posttest, follow-up) when averaged across the levels game-based activities and metacognition.

On the other hand, the results did not reveal a statistically significant effect of the pedagogical intervention, $F_{(1)} = 2.09$, $p = 0.1648$. This suggests that there was no significant overall difference in mean scores between game-based activities and metacognition when collapsed across time. A statistically significant interaction between time factor and pedagogical intervention was observed, $F_{(2)} = 6.02$, $p = 0.0054$, this finding demonstrates that the effect of time on mean scores varied as a function of the pedagogical intervention (*game-based activities vs metacognition*). In other words, the pattern of temporal change differed between the two variables.

Post-Hoc Analysis

The post-hoc analysis revealed a significant difference between pretest and posttest ($t(19) = 5.40$, $p < 0.001$, Hedges'g = 0.64), indicating a moderate-to-large effect size. Post-Hoc Tests for the Main Effect of Time (with Bonferroni Correction): The post-hoc analysis revealed a significant difference between pretest and postest ($t_{(19)} = 5.40$, $p < 0.001$, Hedges' $g = 0.64$), indicating a moderate-to-large effect size. For pretest vs. follow-up: The difference is statistically significant, mean scores at follow-up were significantly higher than at pretest ($t_{(19)} = -5.00$, $p < 0.001$, Hedges' $g = -0.45$). The effect size is moderate, indicating that the improvement was maintained over time.

For postest vs. follow-up: The difference is not statistically significant ($t_{(19)} = 1.877$, $p < 0.227$, Hedges' $g = 0.237$). There is no evidence of a significant change in mean scores between postest and follow-up. In summary, for the main effect of time: There was a significant improvement from pretest to postest, and this improvement was sustained at follow-up.

Post-Hoc Tests for the Time x pedagogical intervention Interaction: The significant interaction indicates that the pattern of change over time differs between the pedagogical intervention game-based activities and metacognition. At Pretest: The difference between game-based activities and metacognition is significant ($t_{(19)}$ = 2.392, p-unc = 0.0272, Hedges' g = 0.6575). At Postest: The difference between game-based activities and metacognition is not significant ($t_{(19)}$ = 0.9914, p-unc = 0.3339, Hedges' g = 0.2984). At Follow-up: The difference between game-based activities and metacognition is not significant ($t_{(19)}$ = 0.388, p-unc = 0.7017, Hedges' g = 0.1014)

The significant interaction and the pairwise comparisons suggest that, although there is no overall difference between game-based activities and metacognition (non-significant main effect), differences between them may emerge at specific time points. Examination of the Figure 3 indicates that the difference between game-based activities and metacognition is more pronounced at the pretest stage (where game-based activities scores are significantly higher), whereas at postest and follow-up the scores of both variables converge.

Summary: Time had a significant impact on overall scores, with improvements observed from pretest to postest and maintenance of these gains at follow-up. Although there was no general difference between the game-based activities and metacognition levels, the significant interaction indicates that their relationship varies over time, specifically, game-based activities appears to start with higher scores than metacognition at pretest, and this difference diminishes at postest and follow-up.

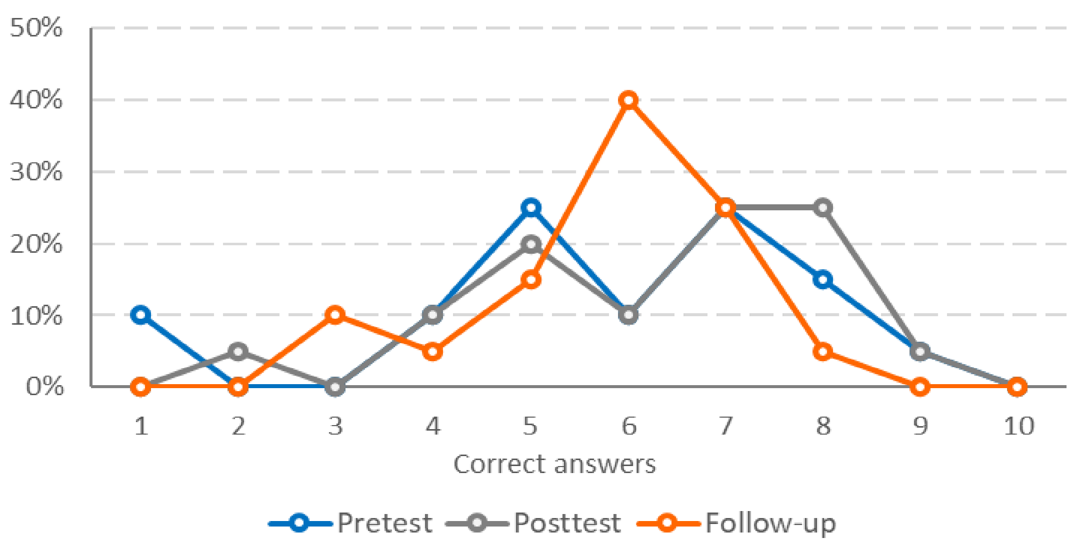
Verification of assumptions results

Normality: The Shapiro–Wilk tests indicated that the assumption of normality was met in most conditions (all $p > 0.05$), although in certain specific conditions, the scores showed significant deviations from normality ($p < 0.05$). However, since ANOVA is relatively robust to moderate violations of normality, the analysis was carried out as planned. The Shapiro–Wilk tests confirmed that the scores in each condition were normally distributed (all $p > 0.05$), thus meeting the assumption of normality.

Homogeneity of Variances: Levene's test for the factor time was not significant (W = 1.123, p =0.328), suggesting that the variances of the scores were homogeneous across the different assessment times. Similarly, Levene's test for the pedagogical intervention was not significant (W = 0.2047, p = 6518), indicating homogeneity of variances between the pedagogical intervention game-based activities and metacognition.

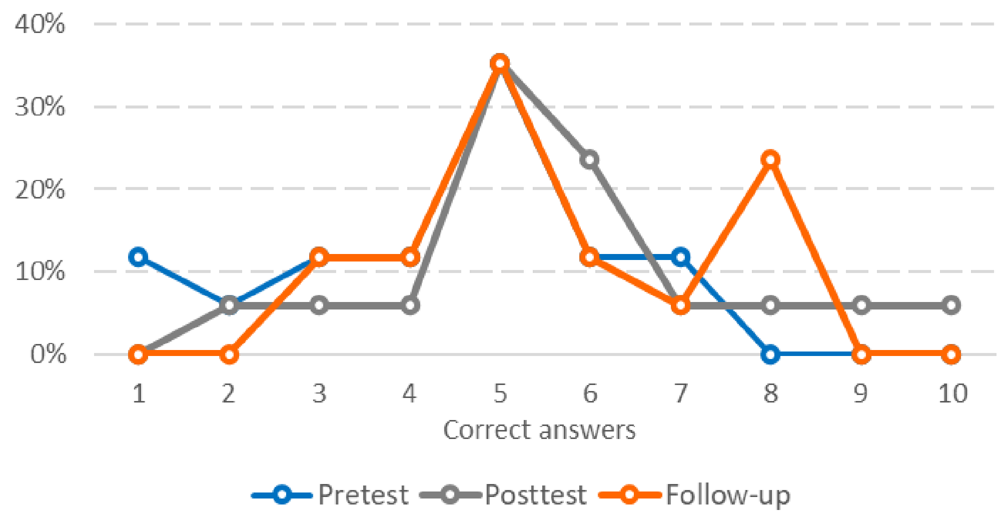
In normality may be violations in some groups, but ANOVA is generally robust to moderate deviations from normality. Homogeneity of Variances: Both variables analyzed met the assumption of homogeneity of variances, suggesting that the variances of the scores were homogeneous across the different assessment times as well as indicating homogeneity of variances between the pedagogical intervention. Sphericity: Likely violated for the Time factor and the time × pedagogical intervention interaction, automatically the Greenhouse–Geisser correction was applied, then the corrected p-values for the effects of time and the pedagogical intervention interaction where calculated. Both confirm the initial ANOVA findings.

Figure 1. Performance of Group 1



Note. Created by the authors based on research findings

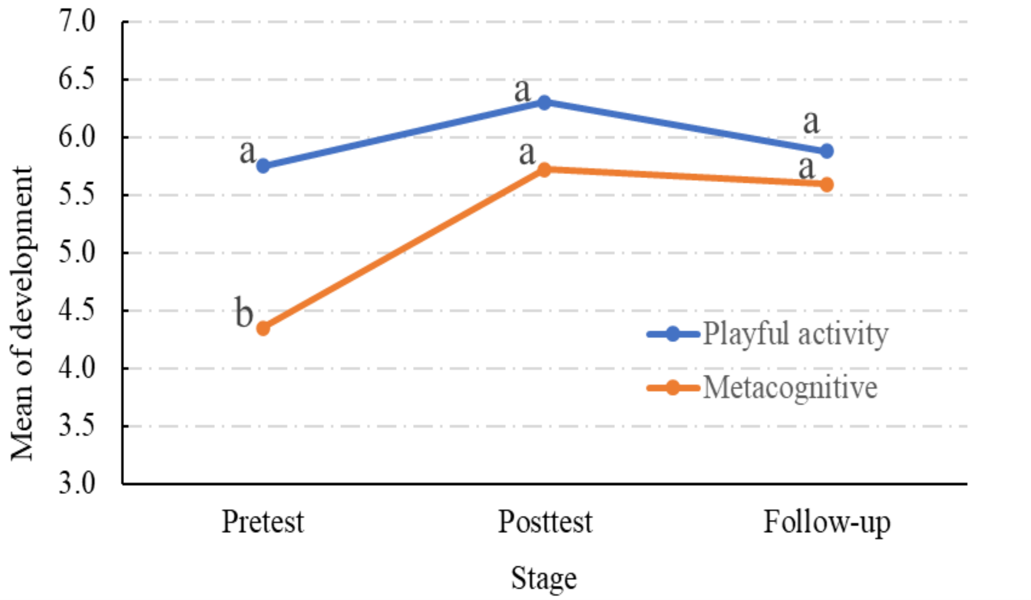
Figure 2. Performance of Group 2



Note. Created by the authors based on research findings.

As can be seen in Figure 3, no significant changes were observed in the performance of participants using the game-based activities across the three stages (pretest, posttest, and follow-up). In contrast, the metacognitive strategy reflected a significant increase in performance after the intervention, which was maintained until the follow-up stage.

Figure 3. Mean performance of participants in both strategies throughout the quasi-experiment. Means that do not share similar subscripts are significantly different ($p < 0.05$).



Note. Created by the authors based on research findings.

Discussion

This research aimed to establish the effectiveness of generating meaningful learning through the metacognitive strategy CRIME compared to the use of game-based activities in the classroom, focusing on statistical problems for sixth-grade students in primary education. The research followed a design with two factors. The between-subjects factor, which had two levels: (1) the CRIME and (2) game-based activities. The within-subjects factor was time, with three levels of measurement: pretest, posttest, and follow-up. The dependent variable was meaningful learning.

Principal findings

Based on the differences found between the pretest and posttest, the learning achieved through the metacognitive strategy workshop was more effective than that reported by the group that worked with game-based activities. Although both groups exhibited improvement, the group that engaged in game-based activities demonstrated a smaller mean gain. When comparing the effects of the posttest with the follow-up, a non-significant decrease in participants' performance was found, reflecting the retention of learning over time. According to Ausubel (2000), this retention suggests meaningful learning.

During the study, the dependent variable of meaningful learning was operationalized through its three key characteristics, which were measured by the within-subjects factor of time (pretest, posttest, follow-up). The implementation of the workshops allowed to observe two of these characteristics directly: (a) intentional and voluntary participation of students in the activities; (b) non-memoristic learning, which was assessed through the presentation of statistical problems in different contexts. The third characteristic, retention of learning, was specifically evaluated by comparing the results from the posttest and the follow-up measurements.

Interpretation in light of the literature

The metacognitive strategy group showed the highest increase in learning after the intervention. This coincides with the differential effect by strategy and with the findings of Plutin-Pacheco and García-López (2016), who found that game-based activities reduce negative emotional effects on a subject but do not improve student performance. The results regarding the metacognitive strategy CRIME align with those previously obtained by Novak

(2013), who taught a course on self-regulated learning. His findings mention that students who remained for the entire semester achieved meaningful learning through metacognition.

The findings on the use of game-based activities are consistent with the contributions of Plutin-Pacheco and García-López (2016). Their report, like this research, indicates that the use of game-based activities led to a positive perception of the subject but did not generate a statistically significant improvement in learning.

In contrast, the study by Güneş & Genç (2021) found that using concrete manipulatives (LEGO bricks) helped students of a comparable age to the participants in this investigation to better understand questions and improve their problem-solving comprehension. Nevertheless, the present study differs in two key aspects: the nature of the game-based learning intervention, which utilizes gameboards instead of LEGOs, and the duration, which spanned eight school days as opposed to eleven weeks.

Conclusions

In conclusion, this research indicates that the metacognitive strategy CRIME is more effective than game-based activities in generating meaningful learning for solving statistical problems among sixth-grade students in primary education. The comparison between the groups' performance before and after the intervention reflects that the most successful strategy was the metacognitive one, with a group improvement of 13.6%, compared to 5.5% for the group that worked with game-based activities.

It is concluded that the metacognitive strategy is supported as a more effective option than game-based activities for the purposes of this research. The findings highlight the importance of metacognitive strategies in fostering meaningful learning and provide evidence for their effectiveness in educational settings. These results contribute to the understanding of how different teaching strategies influence learning outcomes and offer practical insights for educators aiming to enhance student performance in mathematics.

Contributions to Future Lines of Research

Future research should use the information reflected in this article to lead to new questions and future research on the best way to learn to solve statistical problems in primary school. In this sense, it is possible that using a new learning strategy or modify the dosages or type of games could increase the effectiveness percentage presented here.

Another possibility is to investigate whether there are positive effects when using an hybrid approach (the metacognitive strategy and game-based activities as a single strategy), maintaining the context of this quasi-experiment. This would allow for determining if there are positive outcomes in using game-based activities for generating meaningful learning or if the results are equivalent to those presented in this research, which were not statistically significant.

Finally, the possibility of replicating this research with a larger number of participants and, if possible, comparing public and private schools is considered. The intention is to establish the relevance of the strategies, highlighting any differences in learning processes across different contexts.

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