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ORIGINAL

Itinerant Inclusion and Situated Technological Mediation: Democratization of Augmented Reality for Spatial Observation in Limited-Resource Classrooms

Inclusión itinerante y mediación tecnológica situada: democratización de la realidad aumentada para la observación espacial en aulas con recursos limitados

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ABSTRACT
The digital divide continues to limit the incorporation of emerging technologies in public institutions with limited technological resources, especially in scientific areas that require high levels of visual and spatial abstraction. The objective of the study was to evaluate the effect of a didactic intervention based on augmented reality on spatial thinking associated with the comprehension of astronomical content in fifth-grade primary school students. The research was developed under a quantitative approach, with a quasi-experimental design of pre-test and post-test applied to a single group. The sample consisted of 28 students from a public elementary school in Xalapa, Veracruz, Mexico. For data collection, the Analytical Rubric of Astronomical Spatial Thinking was used, validated by expert judgment and with interjudge reliability estimated by Kappa de Fleiss (k = 0.84). The intervention was organized into eight sessions using rotary stations, sharing of a mobile device, printed scoreboards, and complementary analog activities. The results showed an increase in the mean from 5.2 in the pretest to 8.9 in the posttest, with a statistically significant difference according to the Wilcoxon test ($p < 0.001$). It is concluded that augmented reality, integrated through an itinerant inclusion strategy, can favor spatial thinking and democratize technological experiences in classrooms with limited infrastructure.

Keywords: augmented reality, spatial thinking, primary education, digital divide, solar system.

RESUMEN
La brecha digital continúa limitando la incorporación de tecnologías emergentes en instituciones públicas con recursos tecnológicos reducidos, especialmente en áreas científicas que requieren altos niveles de abstracción visual y espacial. El objetivo del estudio fue evaluar el efecto de una intervención didáctica basada en realidad aumentada sobre el pensamiento espacial asociado a la comprensión de contenidos astronómicos en estudiantes de quinto grado de educación primaria. La investigación se desarrolló bajo un enfoque cuantitativo, con diseño cuasi-experimental de preprueba y posprueba aplicado a un solo grupo. La muestra estuvo conformada por 28 estudiantes de una escuela primaria pública de Xalapa, Veracruz, México. Para la recolección de datos se empleó la Rúbrica Analítica de Pensamiento Espacial Astronómico, validada mediante juicio de expertos y con confiabilidad interjueces estimada por Kappa de Fleiss (k = 0.84). La intervención se organizó en ocho sesiones mediante estaciones rotativas, uso compartido de un dispositivo móvil, marcadores impresos y actividades analógicas complementarias. Los resultados evidenciaron un incremento de la media de 5.2 en la preprueba a 8.9 en la posprueba, con diferencia estadísticamente significativa según la prueba de Wilcoxon ($p < 0.001$). Se concluye que la realidad aumentada, integrada mediante una estrategia de inclusión itinerante, puede favorecer el pensamiento espacial y democratizar experiencias tecnológicas en aulas con infraestructura limitada.

Palabras clave: realidad aumentada, pensamiento espacial, educación primaria, brecha digital, sistema solar.

INTRODUCTION

The integration of emerging technologies into basic education has created new opportunities to transform the teaching of scientific content, which has traditionally relied on printed resources, two-dimensional diagrams, and expository explanations. However, this process does not occur under uniform conditions, as many public institutions continue to face limitations in connectivity, device availability, and effective access to digital resources. The digital divide reflects structural inequalities that extend beyond mere possession of technology, encompassing social, economic, and pedagogical factors that affect the meaningful appropriation of digital environments (Alva de la Selva, 2015; Ramírez-Castañeda & Sepúlveda-López, 2018). In this context, technological inequalities have a direct educational impact by restricting students' opportunities for participation, exploration, and learning in resource-limited school settings.

The evolution of the concept of the digital divide has clarified that the issue is not limited to physical access to the internet or devices, but also includes usage skills, the quality of digital experiences, and the institutional capacity to integrate technology with pedagogical intent (Padilla Yaá & Barrera Rojas, 2025). This situation is more pronounced in rural, peripheral, or socially vulnerable schools, where infrastructure limitations can exacerbate learning disparities among student groups (Olarewaju et al., 2021). Additionally, Wang et al. (2024) note that educational inequalities associated with the use of digital devices may be linked to variations in academic performance, underscoring the need to design technological strategies tailored to the actual conditions of institutions rather than idealized models of connectivity.

In this context, augmented reality emerges as a relevant alternative to enhance the learning of abstract content, due to its ability to superimpose digital information onto the physical environment and generate interactive visualization experiences. Akçayır and Akçayır (2017) identify that augmented reality can improve motivation, conceptual understanding, and interaction with learning objects, although they also highlight challenges related to pedagogical design, technological availability, and teacher training. Similarly, Al-Ansi et al. (2023) argue that immersive technologies, such as augmented reality and virtual reality, have seen increasing development in education, mainly due to their potential to create active, visual, and contextualized experiences. This potential has been confirmed by Singh et al. (2024), who report that educational research on augmented reality has grown steadily, especially in areas related to science, visual learning, and interactive environments.

In primary education, augmented reality is particularly significant because it brings complex phenomena closer to the visual and experiential language of students. Marín-Díaz and Sampedro-Requena (2020) highlight that primary students perceive augmented reality as an engaging and useful resource for learning, which can foster a positive attitude toward school activities. In the Mexican context, Salgado Reveles (2023) reports that the use of virtual reality and augmented reality can have a favorable impact on attitudes toward science among primary-level students, an important factor for promoting a more active relationship with scientific knowledge from an early age. This evidence suggests that immersive technologies can add value when integrated into planned didactic sequences rather than as isolated or merely demonstrative resources.

The teaching of natural sciences requires strategies that help represent phenomena that cannot always be directly observed in the classroom. Merino et al. (2015) argue that augmented reality can contribute to the design of teaching-learning sequences in science by facilitating the visualization of structures, processes, and relationships that require high levels of abstraction. This need is particularly evident in the teaching of the solar system, where students must understand rotational and translational movements, scale relationships, orbital trajectories, and relative positions among celestial bodies. Díaz Quesada et al. (2025) state that the teaching of astronomy requires didactic mediations capable of bringing the universe closer to the school experience, so that astronomical phenomena can be interpreted through comprehensible and meaningful resources.

Spatial thinking is a central skill for understanding scientific concepts related to location, orientation, scale, shape, movement, and three-dimensional representation. In basic education, its development enables students to interpret geometric and spatial relationships necessary for understanding natural phenomena and scientific models. Calle-Álvarez and Vargas-Franco (2022) indicate that learning styles and pedagogical strategies influence the development of spatial and geometric thinking in primary school students, making it necessary to implement didactic experiences that connect perception, manipulation, and visual representation. From this perspective, augmented reality can serve as a mediating resource to move from flat observation of printed images to interactive exploration of three-dimensional models.

However, implementing augmented reality in schools with limited resources requires overcoming the assumption that technological innovation depends on the individual availability of devices for each student. In many school contexts, access to digital laboratories, tablets, or stable connectivity is limited, making it necessary to design pedagogical models that are feasible with existing resources. Mobile learning offers a flexible alternative for integrating portable devices into educational practices, provided that their use aligns with clear didactic objectives and appropriate organization of activities (Crompton & Burke, 2018). Therefore, strategies such as rotating stations, cooperative work, and shared device use may represent relevant approaches to democratizing technological experiences without relying on ideal school infrastructures.

Based on this framework, the present study analyzes a didactic intervention mediated by augmented reality aimed at strengthening spatial thinking in primary education students. The proposal is based on a situated technological inclusion strategy, organized through rotating learning stations, shared use of mobile devices, and printed markers for visualizing the solar system. Accordingly, the general objective was to evaluate the effect of a didactic intervention based on augmented reality on spatial thinking related to the understanding of astronomical content in a primary education classroom with limited technological resources.

METHODS

Research Design

The study employed a quantitative approach, using a quasi-experimental pretest-posttest design with a single group. This methodological choice enabled comparison of students' spatial thinking levels before and after the didactic intervention mediated by augmented reality, while maintaining the natural classroom organization and real conditions of school implementation. The independent variable was the itinerant inclusion strategy using augmented reality, while the dependent variable was the level of spatial thinking related to the understanding of astronomical content about the solar system.

Population and Sample

The reference population consisted of students from public primary schools in the municipality of Xalapa, Veracruz, located in contexts with limited technological infrastructure. The sample comprised 28 fifth-grade primary education students, selected by institutional convenience based on group availability, authorization from the educational institution, and the feasibility of conducting the intervention during the school day.

Inclusion criteria required that students were enrolled in fifth grade, had informed consent from their legal guardians, attended classes regularly, and participated in the pretest, intervention, and posttest phases. Exclusion criteria included absence during any of the main phases of the study, withdrawal from the intervention process, or recording absences greater than 15% during the operational phase.

Instrumentation and Data Collection

To measure the level of conceptual appropriation and spatial thinking, the Analytical Rubric of Astronomical Spatial Thinking (RAPEA) was designed to assess students' performance in content related to the solar system. The instrument was structured into five cognitive dimensions: identification of spatial scale, geometric understanding of rotational movement, orbital analysis of translation, abstraction of lunar phases, and mental three-dimensional modeling. Each dimension was scored from 0 to 2 points, resulting in a final scale from 0 to 10 points.

The theoretical and construct validity of the RAPEA was established through expert judgment. The instrument was reviewed by four specialists in educational sciences, who evaluated the relevance, clarity, and coherence of the indicators with respect to the study objective. Additionally, to estimate inter-rater reliability during direct classroom observations, Fleiss' Kappa coefficient was applied in a prior pilot test, yielding a value of k = 0.84, which demonstrates an adequate level of agreement among evaluators.

Intervention Procedure and Itinerant Methodological Flow

The intervention was conducted in three consecutive phases. In the diagnostic phase, the pretest was administered using the RAPEA to establish the baseline of students' spatial thinking. This initial assessment was carried out using traditional printed materials and explanations focused on two-dimensional representations of the solar system.

In the operational phase of itinerant inclusion, a rotating learning station dynamic was implemented, considering the limited availability of technological resources in the classroom. The group was divided into four cooperative subgroups of seven members each. While three subgroups engaged in complementary analog activities, such as field journals, diagrams, and mind maps using printed or reused materials, one subgroup accessed the technological station with augmented reality. At this station, the teacher guided three-dimensional observation using printed markers and an augmented reality application of the solar system. Students interacted with virtual models of the planets, exploring scale relationships, rotational and translational movements, and relative positions among celestial bodies. Each subgroup rotated through the technological station for 20 minutes per session.

In the final evaluation phase, after completing the eight-session didactic sequence, the RAPEA was administered again under conditions similar to those of the pretest. This measurement enabled a comparison of changes in student performance and an assessment of the intervention's effect on the development of astronomical spatial thinking.

Figure 1. Description of phases.

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|                     DIAGNOSTIC PHASE (PRE-TEST)                      |
|     - Initial written assessment with two-dimensional support        |
|     - Baseline score recording on the RAPEA rubric                   |
+----------------------------------------------------------------------+
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                                   v
+----------------------------------------------------------------------+
|                 INTERVENTION PHASE: ITINERANT INCLUSION              |
|     [Subgroup A]   -→   [Station RA-1: Cellular Device]              |
|     [Subgroup B]   -→   [Analog Station 1: Bitácora]                 |
|     [Subgroup C]   -→   [Analog Station 2: Reuse Maps]               |
|     * Systematic rotation every 20 minutes, timed                    |
+----------------------------------------------------------------------+
                                   |
                                   v
+----------------------------------------------------------------------+
|                      EVALUATION PHASE (POST-TEST)                    |
|     - Re-administration of the RAPEA instrument to the entire group  |
|     - Inferential analysis of variations in SPSS (Wilcoxon)          |
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Statistical analysis

The scores obtained in the pretest and posttest were organized in a data matrix. First, descriptive statistics such as means and standard deviations were calculated to characterize the group's performance before and after the intervention. Subsequently, the Shapiro-Wilk normality test was applied to determine the distribution of the data. The results indicated that the distribution did not meet the normality assumption; therefore, the non-parametric Wilcoxon signed-rank test for related samples was used, with a significance level of $p < 0.05$. This procedure allowed for determining whether the differences between the pretest and posttest were statistically significant.

RESULTS

The systematization of the scores obtained through the Analytical Rubric for Astronomical Spatial Thinking (RAPEA) enabled the identification of a favorable change in student performance after the intervention with augmented reality.

Overall, the results show an increase in the level of spatial thinking related to understanding the solar system, particularly in aspects such as the identification of scales, rotational and translational movements, and three-dimensional representation of celestial bodies.

In the pretest, administered before the intervention, the group obtained a mean of 5.2 points out of 10, with a standard deviation of 1.4. This result indicated initial difficulties in interpreting complex spatial relationships using printed resources and two-dimensional explanations. The main limitations were observed in understanding planetary scales and explaining orbital movements, aspects that require visual and spatial abstraction processes.

After implementing the itinerant inclusion strategy mediated by augmented reality, the group's mean in the posttest increased to 8.9 points, with a standard deviation of 0.8. This difference represents an increase of 3.7 points between the initial and final measurements, indicating a significant improvement in the students' overall performance. The reduction in dispersion in the posttest also suggests greater homogeneity in the results achieved by the group after the intervention.

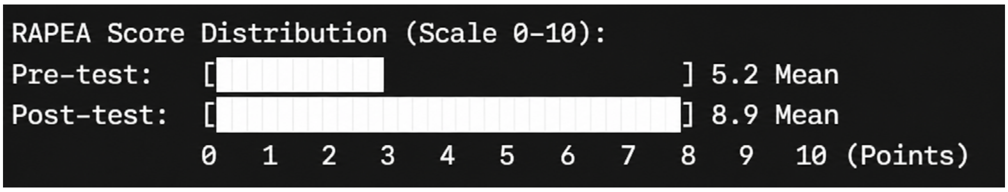
Table 1. Consolidated pretest and posttest results of the RAPEA Rubric.

Study variable (N = 28)	Pretest mean	Posttest mean	Mean difference	Asymptotic significance
Spatial thinking	5.2 ± 1.4	8.9 ± 0.8	+3.7 points	p < 0.001

Source: Own elaboration.

The inferential analysis was performed using the non-parametric Wilcoxon signed-rank test for related samples. The result yielded a value of $Z = -4.68$, with a two-tailed asymptotic significance of $p < 0.001$. Since this value was lower than the established significance level of $p < 0.05$, a statistically significant difference was identified between the pretest and posttest scores. Therefore, the results indicate that the didactic intervention mediated by augmented reality produced a significant improvement in the spatial thinking of the participating students.

Figure 2. Score scheme.



Source: Own creation.

The findings also indicate that the organization by rotating stations enabled the functional use of the available technological resource without requiring an individual device for each student. The cooperative work dynamic allowed all subgroups to access the three-dimensional visualization experience, while complementary analog activities reinforced the interpretation of astronomical content. Overall, the results demonstrate that the itinerant inclusion strategy can be a viable alternative for integrating augmented reality in classrooms with limited technological resources, provided that there is organized didactic planning and adequate teacher mediation.

DISCUSSION

The results obtained indicate that the itinerant inclusion strategy mediated by augmented reality supported the development of spatial thinking in the participating students. The increase in the mean between the pretest and posttest shows that three-dimensional visualization of the solar system helped to overcome some limitations inherent to two-dimensional printed resources. This finding is consistent with García Franco and Taber (2010), who note that learning abstract scientific concepts requires mediations that help students reorganize their prior ideas and construct more comprehensible representations of the phenomena studied. In this case, augmented reality functioned as a visual aid to interpret relationships of scale, location, and movement that are often complex when explained solely through flat images.

The observed improvement can also be interpreted in terms of the value of immersive technologies as resources to enhance the educational experience. Javaid et al. (2024) highlight that virtual reality and other immersive technologies can contribute to educational advancement when integrated with criteria of sustainability and accessibility. Although the present study focused on augmented reality rather than virtual reality, the results indicate an important convergence: immersive technologies should not be evaluated solely based on their technical sophistication, but rather on their capacity to generate viable learning experiences in real-world contexts. In this regard, the use of a shared device and printed markers enabled the technological resource to be adapted to classroom conditions without diminishing its pedagogical potential.

The intervention also provides insights for discussing the role of technology in the assessment and improvement of school learning. Martínez-Comesaña et al. (2023) caution that the incorporation of emerging technologies in primary and secondary education requires a revision of assessment methods, as digital tools alter the ways in which students interact with knowledge. In this study, the RAPEA rubric enabled the assessment of specific dimensions of spatial thinking before and after the intervention, facilitating the observation of changes in the understanding of astronomical content. This reinforces the need for technological experiences to be accompanied by assessment instruments aligned with the skills intended to be developed.

From an inclusion perspective, the findings are relevant because they demonstrate that the digital divide cannot always be addressed solely through the immediate provision of individual devices, but also through pedagogical models that optimize available resources. Vidal-Alaball et al. (2023) argue that digital transformation must consider strategies aimed at reducing gaps in access and use, especially in populations with unequal conditions. Although their analysis is situated in the health sector, their contribution helps to clarify that reducing digital divides requires contextualized solutions. In the educational context, the strategy of rotating stations enabled all students to participate in the augmented reality experience, even when technological infrastructure was limited.

Additionally, Alòs et al. (2024) note that mobile solutions face challenges related to design, implementation, and sustainability, particularly when aiming to promote changes in everyday practices. This observation is pertinent for interpreting the intervention conducted, as the use of mobile devices in the classroom does not in itself guarantee educational improvement. The difference was found in the didactic organization of the resource, the planned rotation of equipment, and the integration of digital and analog activities. Therefore, the results suggest that effective technological inclusion depends as much on the available resources as on the teacher mediation that structures their pedagogical use.

The use of smartphones and mobile devices also highlights the need to consider their modes of use, measurement, and regulation within educational processes. Cendrero-Ugena et al. (2026) indicate that tools for measuring smartphone use provide a better understanding of how children and adolescents interact with these devices. Although the present study did not evaluate mobile phone usage habits, it demonstrates that the device can serve as a pedagogical resource when used with clear objectives, defined timeframes, and teacher guidance. This distinction is important, as educational use of the phone should not be conflated with unplanned technological exposure.

Regarding the methodological design, the results are based on a pretest-posttest approach that allowed for comparison of the group's performance before and after the intervention. Recent quasi-experimental studies have demonstrated the usefulness of this type of design for assessing the effect of interventions applied in real-world contexts, especially when it is not possible to fully control all environmental variables (Alvarado Escobar et al., 2026; Riera Arias et al., 2026). In this article, the quasi-experimental design was appropriate because it allowed work with a natural classroom group, respecting its school dynamics and evaluating the change produced after the didactic sequence.

Similarly, Nguyen and Resna (2026) show that quasi-experimental studies can provide useful information on the effect of formative strategies when pre- and post-intervention measurements are compared. In line with this, the statistically significant difference obtained through the Wilcoxon test supports the relevance of the implemented strategy. Nevertheless, it is necessary to acknowledge that the single-group design limits the possibility of attributing the changes exclusively to the intervention, due to the absence of a control group. Therefore, the results should be interpreted as initial favorable evidence, but not as an absolute generalization for all school contexts.

Finally, the research presents some limitations that should be considered for future studies. The sample consisted of 28 students from a single fifth-grade group, which restricts the generalization of the findings to other institutions, grade levels, or rural contexts with different conditions.

In addition, the intervention was carried out over eight sessions, so it would be appropriate to conduct longitudinal studies that analyze the persistence of learning and the transfer of spatial thinking to other scientific content. It would also be advisable to incorporate designs with control groups, mixed approaches, and qualitative analyses of the student experience, in order to understand not only the extent of performance improvement, but also how students construct meaning during interaction with augmented reality.

CONCLUSIONS

The results of the study indicate that the itinerant inclusion strategy mediated by augmented reality supported the development of spatial thinking in the participating fifth-grade students. The observed difference between the pretest and posttest demonstrated a significant improvement in understanding astronomical content related to the solar system, particularly regarding scales, rotational and translational movements, and the three-dimensional representation of celestial bodies.

The intervention demonstrated that augmented reality can serve as an effective didactic resource for teaching abstract scientific concepts in primary education, provided its use is integrated with clear pedagogical planning. In this context, three-dimensional visualization complemented explanations based on printed materials and facilitated students' ability to establish more comprehensible spatial relationships among the elements of the solar system.

Similarly, the rotating stations model proved to be a viable alternative for integrating technology in classrooms with limited resources. The availability of only one mobile device did not prevent students from accessing the immersive experience, as cooperative organization enabled the distribution of interaction times and the combination of digital activities with analog reinforcement tasks. This demonstrates that technological inclusion depends not only on the number of available devices, but also on teacher mediation and the didactic design of activities.

The study also underscores the value of situated strategies for reducing technological participation gaps in public schools. The itinerant inclusion proposal provided a practical approach to democratizing access to augmented reality resources, preventing infrastructure limitations from becoming an absolute barrier to pedagogical innovation. In this regard, the developed experience may inform future interventions in institutions with similar conditions.

It is recommended to expand this line of research through studies with larger samples, comparison groups, and longitudinal follow-ups to assess learning retention over time. It is also relevant to incorporate mixed-method approaches that analyze the experiences of students and teachers during the use of augmented reality, in order to understand not only changes in performance but also the processes of interaction, motivation, and meaning-making that occur during the intervention.

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