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Inquiry-based learning and magnetism comprehension in socially diverse kindergarten classrooms: Evidence from Roma and general-population children

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ABSTRACT

Sociocultural background shapes early science learning, yet little is known about whether targeted preschool inquiry can reduce conceptual gaps among ethnically marginalised children. This study examined kindergarten children's understanding of magnetism and the extent to which a structured Inquiry-Based Learning (IBL) Teaching-Learning Sequence (TLS) could attenuate differences between a Roma/low-sociocultural-background group and a general-population comparison group. A quasi-experimental pre-test/post-test design involved 50 children aged four to six years: 25 from a Roma/low-sociocultural-background preschool community and 25 from middle-to-high sociocultural backgrounds. The research was conducted during one school week in the 2025–2026 school year, in two public kindergartens located in the same urban area of Greece. Both groups completed an identical six-lesson TLS addressing magnet recognition, material classification, magnetic field permeability, and the size–strength relationship, with contextual links to the Sustainable Development Goals. Descriptive statistics, between-group comparisons, and Welch's independent samples t-test were used to analyse individual variables and composite scores. In relation to the first research question, pre-test results showed a large initial difference between the two groups, with the Roma/low-sociocultural-background group scoring substantially lower than the general-population comparison group on the composite magnetism score, Welch's $t = -10.59$, $p < .001$, Hedges' $g = -2.94$. In relation to the second and third research questions, both groups improved after the TLS, and the initial between-group gap was substantially attenuated. The absolute mean-score gap decreased from 1.96 to 0.48 points on a four-item scale, while the standardised between-group difference decreased from Hedges' $g = -2.94$ to Hedges' $g = -1.31$. In relation to the fourth research question, full convergence was achieved on three of the four conceptual variables: magnet recognition, field permeability, and the size–strength relationship. The remaining difference concerned material classification and may be partly related to interrupted attendance in Group A, although this interpretation remains tentative because lesson-by-lesson attendance was not analysed statistically. The findings suggest that, in this classroom-level intervention, a structured IBL Teaching-Learning Sequence was associated with substantial immediate conceptual gains and attenuation of the initial between-group gap. However, given the small purposive sample, the four-item binary measure, the ceiling effects at post-test, the absence of random assignment, and the lack of a non-intervention control group, the results should be interpreted as promising context-specific evidence rather than as definitive causal proof.

Keywords: inquiry-based learning, magnetism, preschool science education, Roma children, sociocultural background

INTRODUCTION

The relationship between sociocultural background and academic achievement in the natural sciences constitutes one of the most persistent and consequential challenges in contemporary educational research. While science literacy is increasingly recognised as a prerequisite for civic participation, critical thinking, and equitable access to professional life (National Research Council, 2012; UNESCO, 2016), the distribution of science learning opportunities and outcomes remains deeply unequal across socioeconomic and ethnic lines. Research has demonstrated that science achievement gaps are not products of secondary schooling alone; they are detectable as early as kindergarten entry, and the general knowledge gaps present at that stage carry predictive weight well into middle school (Morgan et al., 2016). This finding places the preschool years at the centre of any serious policy discussion about educational equity, and it frames early childhood science education not merely as a pedagogical priority but as a social justice imperative.

The Roma constitute the largest ethnic minority in Europe, and their children are among the most educationally marginalised. According to data gathered across ten European Union member states, the share of Roma children enrolled in early childhood education and care remains significantly below that of the general population, reaching approximately 93% for non-Roma children compared to figures that rarely exceed 50% for Roma children in most national contexts (European Union Agency for Fundamental Rights, 2022). In Greece specifically, survey data indicate an enrolment gap of approximately 70 percentage points between Roma and non-Roma children at the preschool level, with only around 31% of Roma children attending (Rutigliano, 2020). Beyond enrolment, the quality and regularity of attendance further compound the disadvantage: even when Roma children do enrol, irregular participation disrupts the cumulative scaffolding on which early conceptual development depends. These structural inequalities have been theorised within the Bourdieusian framework of cultural capital and social reproduction (Bourdieu, 1977, 1986; Bourdieu & Passeron, 1990), which posits that schooling does not simply transmit knowledge; it reproduces the social order by legitimising the cultural codes of dominant groups.

Within this structural context, the teaching of natural sciences in preschool education presents both a particular challenge and a distinctive opportunity (Ravanis, 2022). Science depends heavily on prior experiential and linguistic capital: children whose home environments have exposed them to scientific vocabulary, exploratory play, and adult-mediated investigation of the physical world tend to arrive at kindergarten with cognitive schema that facilitate further conceptual development (Eshach & Fried, 2005; Vygotsky, 1978). For Roma children, this prior capital is frequently limited not through cognitive deficit but through restricted access to enriched learning environments. Research has consistently shown that socioeconomic disparities in science achievement operate primarily through differences in access to informal science learning opportunities rather than through differences in inherent capacity (Betancur et al., 2018). This distinction carries profound pedagogical implications: it suggests that appropriately designed school-based interventions can function as compensatory mechanisms, providing the experiential scaffolding that unequal social conditions have withheld.

Magnetism occupies a prominent place in early childhood science education and has attracted sustained scholarly attention precisely because of the complex relationship between its intuitive appeal and its conceptual difficulty. Young children are naturally drawn to magnets as objects of wonder, yet they routinely construct misconceptions about their properties, including the widespread belief that all metals are magnetic, that magnetic attraction operates only through direct contact, or that the physical size of a magnet determines its strength (Barrow, 1987; Bar et al., 1997; Driver et al., 1994; Samara & Kotsis, 2024). Kalogiannakis et al. (2018) demonstrated that such misconceptions persist even in structured preschool settings and that purposeful pedagogical intervention is necessary to support conceptual change. More recently, Samara and Kotsis (2023, 2025) showed that STEM-integrated approaches targeting magnetism in kindergarten can produce significant gains in conceptual understanding. What remains absent from this literature, however, is a systematic examination of how sociocultural background mediates magnetism misconceptions and whether Inquiry-Based Learning (IBL) can reduce conceptual gaps across markedly different sociocultural groups.

The present study addresses a specific gap at the intersection of early science education, sociocultural inequality, and inquiry-based pedagogy. Although previous research has examined young children's misconceptions about magnetism and has shown that structured preschool science interventions can support conceptual understanding, limited evidence is available on how such misconceptions appear among Roma/low-sociocultural-background children. Moreover, while Inquiry-Based Learning has been widely promoted as an inclusive pedagogical approach, few studies have examined whether a structured IBL Teaching-Learning Sequence can reduce initial conceptual gaps between marginalised preschool children and their general-population peers. The gap addressed in this study is therefore threefold: the limited evidence on Roma children's early magnetism conceptions, the lack of IBL interventions specifically focused on marginalised preschool learners, and the absence of comparative pre-test/post-test evidence on whether such an intervention can attenuate sociocultural differences in early science learning.

Accordingly, the study was guided by the following research questions:

RQ1. What differences, if any, exist between Roma/low-sociocultural-background kindergarten children and general-population kindergarten children in their initial understanding of magnetism?

RQ2. To what extent is participation in a structured IBL Teaching-Learning Sequence associated with improvement in children's understanding of magnetism in each group?

RQ3. To what extent does the IBL Teaching-Learning Sequence attenuate the initial conceptual gap between the two sociocultural groups?

RQ4. Which magnetism concepts show full convergence after the intervention, and which remain more resistant to change?

THEORETICAL FRAMEWORK

The theoretical framework of this study integrates Piagetian constructivism, Vygotskian sociocultural theory, and Bourdieu's theory of cultural capital not as separate background perspectives, but as complementary lenses that inform the design, analysis, and interpretation of the intervention. Each perspective contributes a distinct explanatory function. Bourdieu's theory frames the expected initial difference between the two groups; Vygotsky's theory informs the mediated and language-supported structure of the IBL sequence; and Piagetian constructivism explains why direct manipulation and cognitive conflict are appropriate mechanisms for conceptual change in preschool magnetism learning.

Bourdieu's theory of cultural capital provides the sociological basis for interpreting the pre-test gap. Children from more privileged sociocultural backgrounds are more likely to enter kindergarten with prior experiences, linguistic resources, and exploratory habits that correspond to the expectations of school science. By contrast, children from marginalised communities may encounter formal science practices, scientific vocabulary, and adult-guided exploration of physical phenomena for the first time in preschool (Betancur et al., 2018; Bourdieu, 1977, 1986; Bourdieu & Passeron, 1990; Morgan et al., 2016). In the present study, this perspective informed the interpretation of the initial differences between the Roma/low-sociocultural-background group and the general-population group. The lower pre-test performance of Group A was therefore not approached as a cognitive deficit, but as evidence of unequal prior access to informal science experiences and school-valued cultural resources.

Vygotskian sociocultural theory informed the pedagogical design of the intervention. The TLS was structured around guided participation, adult mediation, shared language, and collaborative meaning-making. The teacher-researcher's role was not to provide definitions in a transmissive manner, but to support children's movement from immediate observation to more stable scientific meanings through prediction, questioning, experimentation, discussion, and reflection (Mercer, 2000; Vygotsky, 1978). This was particularly important for children with limited prior exposure to scientific vocabulary, because the intervention treated language and conceptual understanding as jointly developing through social interaction. In the analysis and interpretation of the findings, this lens was used to understand not only whether children answered correctly, but also how they justified their answers and whether they referred merely to direct experience or to the experimental procedure as evidence.

Piagetian constructivism informed the choice of magnetism tasks and the intervention's emphasis on direct manipulation and cognitive conflict. Children aged four to six construct early explanations of physical phenomena through active engagement with concrete objects; therefore, magnetism offers developmentally appropriate opportunities for prediction, observation, surprise, and revision of intuitive ideas (Driver & Easley, 1978; Piaget, 1952; Posner et al., 1982). In the TLS, children were repeatedly invited to predict what would happen, test their ideas with real materials, observe outcomes, and reconsider their initial explanations. This was especially important for misconceptions such as the belief that all metals are magnetic, that water or plastic blocks magnetic attraction, or that a larger magnet is necessarily stronger. In this way, the Piagetian lens informed both the design of the experimental activities and the interpretation of post-test conceptual change.

Taken together, the three theories provide an integrated framework for the study. Bourdieu explains why an initial conceptual gap may exist; Vygotsky explains how teacher mediation and language-supported inquiry can make scientific meanings accessible; and Piaget explains how hands-on encounters with contradictory evidence can promote conceptual restructuring. The theoretical framework therefore directly supports the study's central question: whether a structured IBL Teaching-Learning Sequence can attenuate sociocultural differences in preschool children's understanding of magnetism.

Within this theoretical framing, magnetism was selected as an appropriate preschool science domain because it allows children to investigate observable effects through direct manipulation, while also confronting misconceptions that require guided conceptual change (Worth, 2010).

Magnetism occupies a distinctive position in preschool science education. Its observable effects are directly perceptible without sophisticated equipment, rendering the phenomenon both immediately engaging and conceptually tractable for young children. At the same time, the underlying physics involves action at a distance and invisible fields, which systematically generates a characteristic set of misconceptions documented across different cultural and educational contexts (Barrow, 1987; Bar et al., 1997; Driver et al., 1994). The most widely attested misconception is the belief that all metals are attracted to magnets. A second cluster concerns the size–strength relationship, with children commonly assuming that a physically larger magnet necessarily exerts a stronger attractive force. A third category relates to magnetic field permeability, with children typically believing that interposing a medium such as water or plastic will weaken or eliminate the magnetic effect (Samara & Kotsis, 2024). Beyond these content-specific misconceptions, Piaget (1929) documented the tendency of young children to attribute animistic qualities to magnets. Both Kalogiannakis et al. (2018) and Samara and Kotsis (2023, 2025) confirm that these patterns persist in contemporary Greek preschool settings and that deliberate pedagogical design aimed at producing cognitive conflict is required for lasting conceptual change (Posner et al., 1982).

METHODOLOGY

Type and Approach of Research

The study adopted a quasi-experimental pre-test/post-test intervention design, an approach commonly used in naturalistic educational settings where random assignment is not feasible or ethically appropriate (Cohen et al., 2018; Creswell & Creswell, 2018). The design was supported by qualitative evidence from individual semi-structured interviews, children's worksheets, and the researcher's observation journal, allowing methodological triangulation of children's conceptual understanding and classroom participation (Cohen et al., 2018; Creswell & Poth, 2018). Quantitative analysis was used primarily to compare the two groups' conceptual profiles before and after the intervention on four conceptual variables, while qualitative evidence was used to interpret children's explanations, classroom participation, and the possible role of attendance during the Teaching-Learning Sequence.

Because the central research question concerned whether the initial between-group conceptual gap was attenuated after participation in the same TLS, the main inferential analysis focused on between-group comparisons at pre-test and post-test. Pre-to-post changes within each group were reported descriptively, rather than treated as definitive causal estimates, given the absence of a non-intervention control group. The two groups were selected purposively on the basis of their contrasting sociocultural profiles rather than randomly assigned, reflecting the ethical and practical constraints of conducting research with young children from vulnerable populations in naturalistic preschool settings. This design therefore does not aim to establish causal effects with the strength of a randomised controlled trial. Instead, it provides contextually grounded evidence of

Table 1. Participant characteristics by group

Characteristic	Group A – Roma/low-sociocultural background	Group B – General-population comparison group
Number of children	25	25
Age range	4–6 years	4–6 years
Gender	Mixed	Mixed
School type	Public kindergarten	Public kindergarten
Location	Same urban area in Greece	Same urban area in Greece
Sociocultural profile	Socially disadvantaged community with high proportion of Roma pupils	Mainly middle-to-high sociocultural background
Home linguistic background	Roma language varieties and/or Greek; Greek used as language of instruction	Mainly Greek-speaking
Parental socioeconomic indicators	Low socioeconomic resources; limited parental educational attainment reported at community/school level	Middle-to-high socioeconomic background reported at community/school level
Attendance pattern during TLS	Less regular; some children missed one or more lessons	Regular attendance across the TLS
Curriculum followed	Greek national kindergarten curriculum	Greek national kindergarten curriculum

Note. Individual-level parental education and income data were not collected in a form suitable for statistical comparison. Sociocultural background was therefore operationalised at the school-community level, using the demographic composition of each kindergarten, teachers' contextual information, and attendance records.

conceptual change following a structured inquiry-based Teaching-Learning Sequence and allows comparison of learning trajectories between two socioculturally distinct groups.

Location, Time, and Research Subjects

The research was conducted during one school week in the 2025-2026 academic year, in two public kindergartens located in the same urban area of Greece. Purposive sampling was employed, with the two kindergartens selected on the basis of the contrasting sociocultural composition of their student populations. This sampling strategy was appropriate because the study aimed to compare two information-rich preschool contexts rather than to produce statistically representative population estimates (Creswell & Poth, 2018; Patton, 2015).

Group A comprised 25 children attending a kindergarten serving a socially disadvantaged community with a high proportion of Roma pupils. In the analysis, this group is referred to as the Roma/low-sociocultural-background group, not to imply that Roma identity itself explains children's initial performance, but to describe the intersection of ethnicity, socioeconomic disadvantage, limited prior access to formal early childhood education, and irregular attendance patterns in this specific educational setting. Group B comprised 25 children from different public kindergartens in the same urban area, drawn mainly from families of middle-to-high socioeconomic standing and treated in the analysis as the general-population comparison group. The comparison therefore concerns two differently situated preschool communities rather than an essentialised contrast between Roma and non-Roma children. The characteristics of the two groups are summarised in **Table 1**.

The attendance pattern was especially relevant because the TLS was cumulative: later activities built directly on the concepts introduced in earlier lessons. Attendance was therefore recorded at the classroom level during the six-lesson intervention and used qualitatively to interpret post-test performance, particularly the residual difficulty observed in Group A on the material-classification item. However, because attendance was not manipulated experimentally and was not included as an independent quantitative variable, it is treated as a contextual explanatory factor rather than as a causal predictor.

Parental and institutional consent was obtained before the commencement of data collection, and all procedures were conducted in accordance with ethical expectations for research with young children in educational settings (Creswell & Poth, 2018).

Teaching-Learning Sequence

The instructional intervention consisted of a six-lesson Teaching-Learning Sequence designed according to the principles of Inquiry-Based Learning and organised in a progressive conceptual structure informed by Bloom's taxonomy (Kotsis, 2024a, 2024b). The sequence was implemented during one school week in both kindergartens. Each lesson lasted approximately 35–45 minutes, a duration considered appropriate for preschool children's attention span and classroom routines. The same researcher-teacher delivered all six lessons in both settings, thereby reducing instructor-related variation between the two groups. The regular classroom teacher was present during the activities and supported classroom management, but the instructional prompts, demonstrations, questioning sequence, and assessment procedures were led by the researcher-teacher.

The six lessons were organised around four core magnetism concepts: magnet recognition, classification of magnetic and non-magnetic materials, magnetic field permeability through intervening materials such as water and plastic, and the relationship between magnet size and magnetic strength. The lessons followed a repeated inquiry cycle consisting of prediction, hands-on testing, observation, discussion, and reflection (Kotsis et al., 2025). Children first explored magnets and described what they observed. They then tested different classroom materials, compared magnetic and non-magnetic objects, investigated whether magnetic attraction could act through water or plastic, and finally compared magnets of different sizes and strengths in order to challenge the common misconception that larger magnets are necessarily stronger.

The materials used during the TLS included different types and sizes of magnets, paper clips, plastic objects, wooden objects, metallic and non-metallic classroom materials, transparent containers with water, illustrated worksheets, and simple recording

Table 2. Pre-test performance by group across all four conceptual variables

Variable	Group A – Roma (n = 25)	Group B – General (n = 25)	χ^2 / Welch's t (pre-test)
Magnet recognition	2/25 (8%)	25/25 (100%)	$\chi^2 = 42.6$, $p < .001$
Material classification	1/25 (4%)	22/25 (88%)	$\chi^2 = 38.8$, $p < .001$
Field permeability (water/plastic)	17/25 (68%)	21/25 (84%)	$\chi^2 = 1.75$, $p = .185$
Size–strength belief (correct)	0/25 (0%)	0/25 (0%)	— (zero variance)
Total score – Mean (SD)	**0.80 (0.71)**	**2.76 (0.60)**	**$t = -10.59$, df = 46.7 $p < .001$**

sheets appropriate for preschool children. Activities were conducted mainly in small groups, with opportunities for individual prediction and whole-class discussion. The small-group format allowed children to manipulate the materials directly, verbalise their ideas, observe peers' predictions, and revise their explanations through shared inquiry.

To support implementation fidelity, the same lesson sequence, materials, guiding questions, and assessment procedures were used in both groups. The researcher-teacher followed the same instructional structure in each kindergarten and recorded implementation notes in an observation journal after each lesson. These notes included children's participation, difficulties observed during the activities, deviations from the planned sequence, and attendance patterns. In this way, the TLS was implemented as consistently as possible across the two classroom contexts, while still respecting the natural routines of preschool teaching.

Data Collection

Three instruments were used. The primary instrument was an individual semi-structured interview administered as both pre-test and post-test. The interview was conducted as a structured dialogue supported by physical objects, so that children's responses would reflect conceptual understanding rather than verbal facility alone. The same four core questions were used before and after the intervention, with the same materials and in the same order. These questions targeted the four conceptual variables: magnet recognition, material classification, field permeability through water or plastic, and the size–strength relationship. The four interview questions are presented verbatim in **Appendix**.

Each child was interviewed individually in a familiar school setting. The researcher presented the relevant objects, asked the fixed question, and allowed the child to respond verbally and/or by pointing, selecting, or manipulating the materials. Follow-up prompts were limited to neutral clarification, such as "Can you show me?" or "Why do you think so?", and no corrective feedback was given during the pre-test or post-test. The second instrument consisted of illustrated non-verbal worksheets completed during the intervention lessons. The third instrument was the researcher's systematic observation journal, maintained throughout the sequence to record participation, notable explanations, implementation issues, and attendance.

Data Analysis

For statistical analysis, each interview item was coded as a binary outcome measure, with 0 indicating an incorrect response and 1 indicating a correct response. A composite total score was computed as the sum of correct responses across the four items, producing a possible score range from 0 to 4. Group differences on individual variables were analysed using chi-square tests, with Fisher's exact test considered where cell frequencies were very small or where response distributions approached extreme values. To improve the interpretation of practical significance, effect sizes were also calculated. For categorical comparisons, Cramer's V was used to estimate the magnitude of between-group differences. For total-score comparisons, Welch's independent samples t-test was used because of unequal group variances, particularly at post-test, and the magnitude of mean differences was interpreted using Hedges' *g*. The reduction in Welch's *t*-statistic from pre-test to post-test was used only as a descriptive indicator of convergence, not as a formal effect-size measure. The POWER variable at post-test exhibited zero variance and was therefore reported descriptively only. All analyses were conducted using jamovi (Version 2.7; The jamovi project, 2025) and R (Version 4.5; R Core Team, 2025).

RESULTS

Pre-Test Performance: Initial Conceptual Profiles

Before presenting the results, it is important to clarify that the study did not include a non-intervention control class. Both Group A and Group B participated in the same six-lesson IBL Teaching-Learning Sequence, delivered by the same researcher-teacher using the same materials, lesson structure, inquiry cycle, and assessment procedures. Group B therefore functioned as a general-population comparison group rather than as a traditional control group. The purpose of the comparison was to examine whether the same IBL sequence was associated with different starting points, learning gains, and post-test convergence across two socioculturally distinct kindergarten communities.

RQ1: Initial Differences in Magnetism Understanding

Prior to the intervention, the two groups displayed clearly different conceptual profiles across the four assessed magnetism variables. **Table 2** summarises the pre-test scores and corresponding inferential statistics.

With respect to magnet recognition, 23 of the 25 Roma children (92%) were unable to identify the object as a magnet and had never previously encountered the word in any context. All remaining Group A children attributed the attraction phenomenon to supernatural agency; a representative response was: 'The teacher is doing magic.' By contrast, all 25 children in Group B correctly

Table 3. Post-test performance by group across all four conceptual variables

Variable	Group A – Roma (n = 25)	Group B – General (n = 25)	Post-test outcome
Magnet recognition	25/25 (100%)	25/25 (100%)	Full convergence
Material classification	13/25 (52%)	25/25 (100%)	Residual gap associated with attendance discontinuity
Field permeability (water/plastic)	25/25 (100%)	25/25 (100%)	Full convergence
Size–strength belief (correct)	25/25 (100%)	25/25 (100%)	Full convergence (zero variance)
Total score – Mean (SD)	**3.52 (0.51)**	**4.00 (0.00)**	**$t = -4.71$, $df = 24.0$, $p < .001$**

identified the magnet prior to instruction, reflecting the richer informal science exposure of their home environments ($\chi^2 = 42.6$, $df = 1$, $p < .001$). A similar pattern obtained for material classification: only one child in Group A (4%) correctly distinguished magnetic from non-magnetic materials prior to instruction, compared with 22 children in Group B (88%; $\chi^2 = 38.8$, $df = 1$, $p < .001$). For field permeability, the pre-test gap was considerably smaller and did not reach statistical significance ($\chi^2 = 1.75$, $df = 1$, $p = .185$): 17 children in Group A (68%) and 21 in Group B (84%) already held the correct conception. Notably, the permeability question proved counterintuitive not only for children but also for several adult educators present during the intervention, the majority of whom initially believed that water would block the magnetic field. The size–strength variable showed zero variance at pre-test: all 50 children in both groups held the incorrect belief that a physically larger magnet is necessarily stronger. In the present sample, this misconception appeared across both sociocultural groups, suggesting that it may be less dependent on prior sociocultural background than the other magnetism concepts examined. The total pre-test score further quantified the initial disparity: Group A achieved a mean of 0.80 (SD = 0.71) correct responses out of four, compared with 2.76 (SD = 0.60) for Group B (Welch's $t = -10.59$, $df = 46.7$, $p < .001$).

RQ2: Improvement in Magnetism Understanding After the IBL Teaching-Learning Sequence

Following the one-week TLS, both groups showed marked improvement across all variables. **Table 3** summarises the post-test outcomes.

These results address RQ2 by showing that both groups improved after participation in the IBL TLS, and they also begin to address RQ4 by indicating three of the four assessed magnetism concepts reached full convergence at post-test.

Full convergence was achieved on three of the four variables. All 25 children in Group A reached ceiling performance on magnet recognition (100%), identical to Group B. For field permeability, all 50 children answered correctly at post-test. For the size–strength variable, all 50 children in both groups achieved the maximum score, having revised the universal pre-test misconception through the empirical disconfirmation built into Lesson 3; children across both groups expressed explicit surprise when the smaller magnet outperformed the larger one, confirming the effectiveness of the designed cognitive conflict. The only post-test variable on which a difference remained was material classification. In Group A, 13 of 25 children correctly distinguished magnetic from non-magnetic materials, whereas all children in Group B did so. Classroom records and the researcher's observation journal indicated that the remaining difficulty in the material-classification task was concentrated among Group A children whose participation in the six-lesson sequence had been interrupted by one or more absences. By contrast, the Group A children who attended the full sequence were able to complete the classification task successfully. This pattern suggests that the residual post-test gap was not evenly distributed across the Roma/low-sociocultural-background group, but was associated with discontinuity of participation in the instructional sequence. Attendance therefore appears to have played an important mediating role in the extent to which children benefited from the TLS. However, because attendance was not experimentally controlled, this interpretation should be understood as a classroom-level explanation rather than as a definitive causal claim. A further qualitative difference was observed in the justification of responses.

When asked "What made you change your mind?", children in Group A predominantly offered experiential justifications, such as:

> "Well, I saw it stick."

Children in Group B more frequently cited the experimental procedure itself, using responses such as:

> "The experiment."

> "The test we did."

A particularly articulate Group B response was:

> "It doesn't stick to the plastic; the force passes through it and grabs the paper clip."

RQ3 and RQ4: Attenuation of the Initial Gap and Concepts Showing Convergence or Remaining Difficulty

In relation to RQ3, **Tables 4** through **6** present the descriptive statistics, between-group comparisons, and Welch's t-test outcomes for the composite total scores in order to examine whether the initial gap was attenuated after the TLS. In relation to RQ4, the same results identify which conceptual variables reached full convergence and which remained sources of residual difference. Where applicable, effect sizes are also reported to indicate the practical magnitude of the observed between-group differences.

Table 4. Descriptive statistics for the total composite score by group at pre- and post-test

Group / Time point	N	Mean	SE	Mdn	SD	Min – Max
Group A (Roma), Pre	25	0.80	0.141	1	0.71	0 – 3
Group B (General), Pre	25	2.76	0.119	3	0.60	1 – 3
Group A (Roma), Post	**25**	**3.52**	**0.102**	**4**	**0.51**	**3 – 4**
Group B (General), Post	**25**	**4.00**	**0.00**	**4**	**0.00**	**4 – 4**

Table 5. Between-group comparisons and effect sizes for individual conceptual variables at pre-test

Variable	Test / statistic	p	N	Effect-size interpretation
RECOGNITION (pre)	$\chi^2 = 42.6$	< .001	50	Very large initial gap, Group B ahead
MATERIALS (pre)	$\chi^2 = 38.8$	< .001	50	Very large initial gap, Group B ahead
WATER (pre)	$\chi^2 = 1.75$	.185	50	No statistically significant pre-test difference
POWER (pre & post)	Not computed	—	50	Zero variance; all children held the same misconception at pre-test and reached the correct response at post-test

Table 6. Welch's independent samples t-test for total score at pre- and post-test

Comparison	Welch's t	df	p	Effect size	Interpretation
TOTAL_PRE	−10.59	46.7	< .001	Hedges' g = −2.94	Very large initial between-group difference, with Group B scoring higher
TOTAL_POST	−4.71	24.0	< .001	Hedges'g = −1.31	Between-group difference remained statistically significant, but its magnitude was substantially reduced after the intervention

The composite total score analysis shows substantial pre-to-post improvement in both groups. Group A began with a mean score of 0.80 correct responses out of four and reached 3.52 at post-test, corresponding to an increase from 20% to 88% of the maximum possible score. Group B began with a mean score of 2.76 and reached 4.00 at post-test, corresponding to an increase from 69% to 100%. In absolute terms, Group A improved by 2.72 points, whereas Group B improved by 1.24 points.

These descriptive results indicate that the lower-starting group showed the larger observed gain following the TLS. Group A improved by 2.72 points, whereas Group B improved by 1.24 points. This pattern is educationally meaningful because it suggests that the group with the lowest initial performance benefited substantially from the intervention. However, the statistical interpretation of this pattern requires caution.

A central measurement limitation of the present study is that the composite score was based on only four binary items. The total score therefore had a restricted possible range from 0 to 4, and each individual item could take only two values, correct or incorrect. As a result, the post-test data were especially vulnerable to ceiling effects. This was evident in the fact that the median post-test score for both groups was 4, the maximum possible score. In addition, three of the four individual conceptual variables reached full convergence at post-test, and the POWER variable showed zero variance because all children in both groups gave the correct response after the intervention. Under these conditions, inferential statistics should not be interpreted as providing fine-grained measurement of conceptual development.

For this reason, the post-test results are interpreted primarily as evidence of immediate classroom-level conceptual convergence on the assessed items, rather than as precise estimates of the magnitude of learning. The persistence of a statistically significant post-test difference in the composite score, Welch's $t = -4.71$, $df = 24.0$, $p < .001$, should also be read in light of the restricted measurement scale and the zero variance in Group B at post-test. The statistically significant difference was driven entirely by the remaining MATERIALS item, on which Group A did not reach ceiling performance. Therefore, the findings show substantial but not complete convergence: full convergence occurred on magnet recognition, field permeability, and the size–strength relationship, while material classification remained the only source of residual difference.

Accordingly, **Figure 1** should be interpreted as a descriptive visualisation of the reduction in the initial gap, not as evidence of full statistical equivalence between the two groups. The figure illustrates that the initial difference between groups became much smaller after the TLS, but the short four-item binary scale and post-test ceiling effects limit the precision with which this reduction can be quantified.

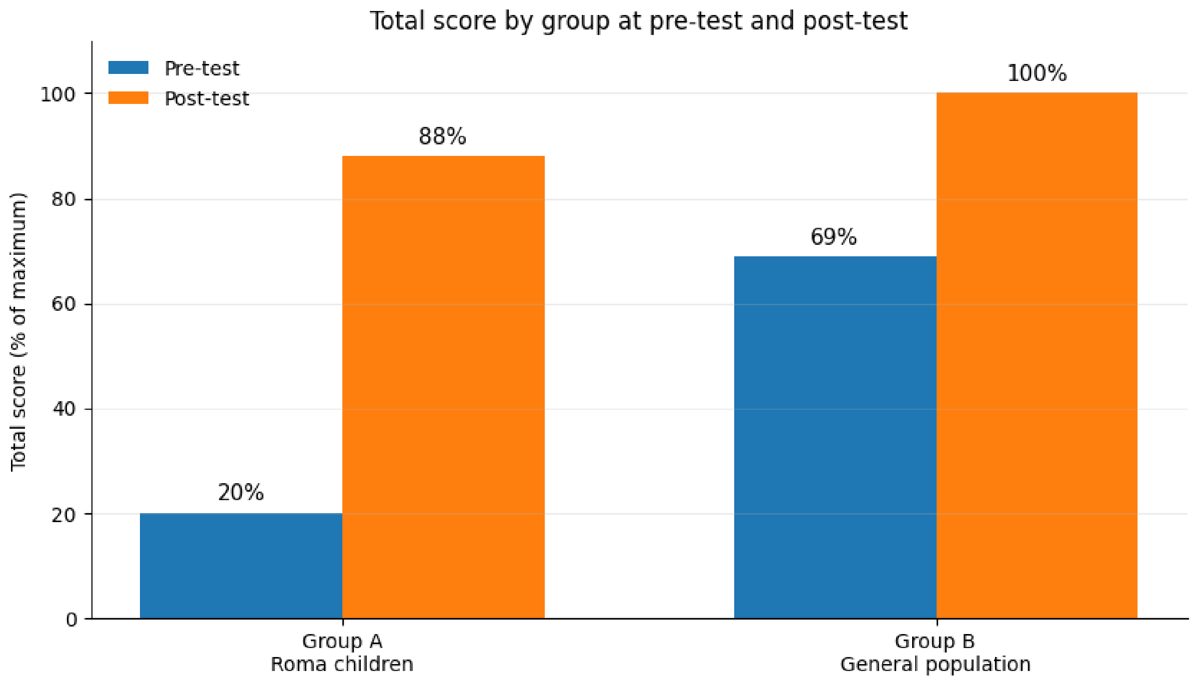

Figure 1. Total score as a percentage of the maximum (out of 4 items) by group at pre- and post-test (Source: Authors' own elaboration)

DISCUSSION

The results provide promising classroom-level evidence that the IBL teaching-learning sequence was associated with conceptual change in preschool science education. Both groups showed clear pre-to-post improvement across the four conceptual variables, and three of the four variables reached full convergence at ceiling level. This outcome is consistent with the broader literature suggesting that structured hands-on investigation and inquiry-oriented learning sequences can support young children in constructing meaningful scientific understanding even of phenomena that are not directly intuitive (Gavrilas et al., 2024; Greenfield, 2015; Harlen & Qualter, 2018). However, because the study was conducted with a small purposive sample and without random assignment or a separate control group, the findings should be interpreted as promising intervention evidence rather than as definitive proof of causal effectiveness. The complete elimination of the size–strength misconception across both groups is consistent with Posner et al.'s (1982) conceptual change model, according to which prior conceptions may be revised when learners encounter contradictory empirical evidence within a supportive pedagogical structure. In the present study, the comparison between magnets of different sizes and strengths created such a cognitive conflict and allowed children to reconsider the assumption that a larger magnet is necessarily stronger. Recent evidence reinforces that guided inquiry interleaved with well-timed explanation is more consistently effective for conceptual understanding than either unguided discovery or didactic instruction alone (Areepattamannil, 2025), a principle reflected in the architecture of the present TLS. The contextualisation of activities through the SDGs appeared to confer contextual relevance on content that might otherwise have remained disconnected from children's lived experience, drawing even the most hesitant Group A participants into sustained engagement, consistent with the argument that contextually anchored tasks lower the effective threshold of prior capital required for meaningful participation (French, 2004; Raven & Wenner, 2023). However, the SDG framing should be interpreted as a contextual support for engagement and relevance, rather than as a separately measured cause of the observed conceptual gains.

The pre-test data were consistent with the theoretical account of sociocultural background as an important mediator of prior scientific knowledge. The large, statistically significant initial gap between groups is theoretically interpretable within Bourdieu's framework of cultural capital: children in Group B had benefited from informal adult-mediated exposure to magnets and arrived with a partially developed scientific lexicon, while Group A children had simply not had access to the informal science learning environments through which such capital is ordinarily accumulated (Betancur et al., 2018; Morgan et al., 2016). This is not a deficit of cognitive capacity but a deficit of cultural exposure, a distinction of fundamental ethical importance. The post-test data suggest that, in this classroom context, the initial gap was not fixed. The between-group difference on the composite score decreased from 1.96 points at pre-test, where Group A scored 0.80 and Group B scored 2.76, to 0.48 points at post-test, where Group A scored 3.52 and Group B scored 4.00. In percentage terms, the absolute mean-score gap decreased from 49 percentage points of the maximum possible score to 12 percentage points. This provides a more transparent descriptive indication of gap attenuation.

The reduction in Welch's t from −10.59 at pre-test to −4.71 at post-test is also reported as a descriptive indicator of convergence, but it is not treated as an effect-size measure. The formal standardised effect-size estimate likewise decreased, with Hedges' g changing from −2.94 at pre-test to −1.31 at post-test. Thus, although the post-test difference remained statistically significant, the magnitude of the between-group difference was substantially smaller after the intervention. These findings support the more cautious conclusion that the structured IBL sequence was associated with substantial attenuation, but not complete elimination, of the initial conceptual gap.

This pattern is consistent with research suggesting that high-quality early childhood education and inclusive, structured pedagogical interventions can reduce the impact of unequal prior learning opportunities, particularly when children are given access to guided, cumulative, and meaningful classroom experiences (Ainscow, 2005; OECD, 2025; Sylva et al., 2004). However, because the present study used a small purposive sample, a four-item binary measure, and no non-intervention control group, the results should be interpreted as context-specific evidence of gap attenuation rather than as definitive causal proof.

A meaningful qualitative difference nonetheless persisted in the form of scientific reasoning. Children in Group A predominantly offered experiential justifications anchored in direct perception, while Group B children more frequently cited the investigative procedure itself. This distinction reflects the difference between empirical learning and procedural scientific literacy, the capacity to recognise the experiment as the epistemic warrant for a conclusion and is consistent with Vygotsky's (1978) account of the linguistic mediation required to elevate concrete experience to the level of generalisation. Additional scaffolding of scientific language, beyond what a one-week intervention can provide, is needed to fully close this reasoning gap.

A further issue concerns the possible role of attendance regularity in children's learning during the TLS. Classroom observations and the researcher's journal indicated that the residual post-test difficulty in Group A was concentrated mainly in the material-classification item and appeared to involve children whose participation in the six-lesson sequence had been interrupted. This observation is pedagogically plausible because the TLS was cumulative: later classification activities depended on experiences introduced and revisited in earlier lessons. However, because the study did not include a detailed numerical attendance analysis for each lesson and did not systematically match each child's post-test errors to the exact lesson or content missed, attendance should be interpreted as a possible contextual factor rather than as a demonstrated causal explanation.

This cautious interpretation is nevertheless consistent with broader evidence that irregular participation in early childhood education can reduce children's access to cumulative learning opportunities, particularly in Roma and socially disadvantaged communities. European-level evidence has identified low preschool participation and attendance as persistent barriers affecting Roma children's educational trajectories, while UNICEF Greece has similarly highlighted the structural barriers that limit Roma children's regular access to formal education (European Parliament, 2023; UNICEF Greece, 2022). In the present study, the attendance-related observations therefore help contextualise the residual post-test gap, but they do not provide sufficient evidence to conclude that attendance alone caused the remaining difference. Future studies should record lesson-by-lesson attendance, analyse its relationship with item-level post-test performance, and examine whether missed lessons correspond directly to the concepts that remain difficult for children.

An incidental classroom observation during the intervention suggests a further issue that deserves cautious consideration. Several adult educators present during the activities initially expected water to block the magnetic effect, indicating that misconceptions about magnetism may not be limited to children. Because this observation was informal and was not collected through a systematic teacher-assessment instrument, it should not be treated as empirical evidence about teachers' science knowledge in the present study. Nevertheless, it is consistent with wider research showing that early childhood educators may experience difficulties with science content knowledge and with the confident implementation of inquiry-based science teaching (Chen et al., 2022; Evagorou et al., 2024). This point is particularly important in socially disadvantaged contexts, where children may have fewer opportunities for informal science learning outside school. In such settings, teacher content knowledge and pedagogical confidence become especially important conditions for equitable access to early scientific literacy. Recent evidence also shows that professional development can help align early childhood science teachers' beliefs and practices with children's learning outcomes, reinforcing the importance of sustained teacher support in this field (Chen et al., 2025). Teacher professional development in both science content knowledge and IBL pedagogy should therefore be viewed as an important structural support for equitable early science education.

The present study is subject to several methodological limitations that define the scope of its conclusions. The sample of 50 children is appropriate for classroom-level and within-study interpretation, but it is not sufficient for broad statistical generalisation. The study was conducted in two public kindergartens in a single urban area of Greece, selected purposively because of their contrasting sociocultural profiles; therefore, the findings should be transferred to other Roma, low-socioeconomic, or general-population preschool contexts with caution. In addition, the study did not include a separate non-intervention control group, and the two groups were not randomly assigned. As a result, the observed gains cannot be attributed to the teaching-learning sequence with the same causal strength as in a randomised experimental design. The intervention also lasted only one school week, and no delayed post-test was administered. Consequently, the study can document immediate post-intervention conceptual gains, but it cannot determine whether these gains were retained over time. These limitations do not diminish the educational value of the findings; rather, they indicate that the results should be interpreted as promising, context-specific evidence of conceptual improvement and gap attenuation following a structured IBL sequence. Because Group A was purposively selected from one socially disadvantaged school community, the findings should not be generalised to all Roma children or to all Roma educational contexts. They should instead be understood as evidence from a specific preschool setting in which ethnicity, socioeconomic disadvantage, limited prior science exposure, and irregular attendance intersected.

CONCLUSIONS

This study investigated whether sociocultural background was associated with kindergarten children's initial understanding of magnetism and whether participation in a structured Inquiry-Based Learning Teaching-Learning Sequence was followed by attenuation of the conceptual gap between Roma/low-sociocultural-background children and children from a general-population comparison group. Within the limitations of this classroom-level quasi-experimental study, the findings provide promising evidence that unequal prior access to informal science-learning opportunities was associated with marked differences in children's initial conceptual knowledge.

Following the six-lesson inquiry-based sequence, both groups demonstrated substantial immediate improvement. The Roma/low-sociocultural-background group increased its mean performance from 20% to 88% of the maximum possible score, while the general-population group increased from 69% to 100%. The initial absolute gap decreased from 49 to 12 percentage points, and full convergence was observed in magnet recognition, magnetic-field permeability, and the relationship between magnet size and strength. Material classification remained the only concept on which a difference persisted. Classroom observations suggest that interrupted attendance may have contributed to this residual difficulty, although this interpretation remains tentative because lesson-by-lesson attendance was not included in the statistical analysis.

The findings indicate that structured inquiry-based preschool science teaching can provide children from contrasting sociocultural backgrounds with meaningful opportunities for prediction, direct experimentation, discussion, and conceptual revision. The lower initial performance of the Roma/low-sociocultural-background group should therefore not be interpreted as evidence of limited learning capacity, but as reflecting unequal prior access to scientific experiences and school-valued linguistic and cultural resources. At the same time, the remaining differences in children's scientific explanations indicate that short-term conceptual convergence does not necessarily imply equivalent development of scientific language or procedural reasoning. Longer and more sustained scaffolding may be required to support children in moving from experience-based statements to explicit evidence-based scientific explanations.

The study also highlights the importance of regular participation and teacher preparation. A cumulative Teaching-Learning Sequence can only provide its full benefit when children are able to participate consistently, while effective inquiry-based science teaching requires educators with adequate science-content knowledge and confidence in facilitating investigation and conceptual discussion. Equitable early science education therefore depends not only on appropriate pedagogical interventions but also on structural support for attendance and sustained professional development for early childhood teachers.

These conclusions must be interpreted cautiously because the study involved a small purposive sample from two kindergartens, lacked random assignment and a non-intervention control group, employed a short four-item binary assessment, and measured only immediate post-intervention performance. Future research should use larger multi-site samples, broader assessment instruments, delayed post-tests, and systematic lesson-by-lesson attendance data. Longitudinal research is also needed to examine whether early inquiry-based science experiences produce sustained conceptual and scientific-reasoning benefits as children progress into primary education.

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APPENDIX

Semi-Structured Interview Questions

The following four questions were administered individually to each child before and after the Teaching-Learning Sequence. The same questions, materials, and order of presentation were used at both time points.

Question 1: Magnet recognition

What is this object? Do you know what it is called?

Question 2: Material classification

Which of these objects do you think will stick to the magnet? Can you show me?

Question 3: Magnetic field permeability

Do you think the magnet can still pull the paper clip if there is water or plastic between them? What do you think will happen?

Question 4: Size–strength relationship

Which magnet do you think is stronger, the larger one or the smaller one? Why do you think so?