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Promoting relational thinking in preschoolers (ages 3–5) through participatory science learning: insights from RMTS with Roma children

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The study examined the development of relational thinking in children aged 3–5 years within a Roma community using the relational matching-to-sample task. Following a four-month period of participatory science learning, there was a twofold increase in the proportion of relational choices made by the children. The teachers and assistant teachers deliberately encouraged child participation in science activities, while adhering to the established state curriculum. This emphasis on child involvement in science activities was discussed as a potential factor contributing to a domain-general shift in relational thinking, an effect not observed in the control group of children from the same community.

KEYWORDS

relational thinking, relational shift, relational matching-to-sample task, child participation, inclusive science education, Roma education

1 Introduction

Despite being a protected right under the United Nations Convention (Woodman et al., 2023) and recognized as both a core element (Love and Horn, 2021) and a best practice in inclusive education (Esteban, 2022), child participation is seldom examined concerning its connection to science learning and STEM education.

Existing research examines how science secondary education contributes to child participation in community life in terms of decisions and attitudes. For instance, it has been demonstrated that engaging in a physics project investigating the reasons for reconstructing footpaths can enhance children's inclination to participate in community decision-making processes and employ scientific knowledge to impact society positively (Varis et al., 2018). Similarly, discussions held in small groups concerning misleading vaccination claims have been shown to influence students' attitudes toward vaccination, even affecting parental decisions regarding their children's vaccination status (Cetinkaya and Saribas, 2022). Additionally, research has explored how extracurricular activities and student assignments related to socio-scientific issues can foster environmental citizenship (Iversen and Jónsdóttir, 2019), particularly when integrated with local socio-cultural traditions (Häyrynen et al., 2021).

Considerably less is understood about the inverse relationship, namely, how child participation can act as a catalyst for science learning and education. Valuable insights from the Henderson Creek project affirm that children's involvement in local community initiatives aimed at conserving the creek has enhanced their comprehension of intricate scientific concepts, such as biological equilibrium (Roth and Lee, 2004). Notably, this involvement has yielded positive outcomes for children with special needs, girls, and minority children, expanding their science literacy and opening doors for further research in inclusive science education. However, it remains uncertain whether the knowledge acquired in this project fosters adaptable conceptual thinking, generalization, and knowledge transfer across diverse contexts (key educational goals as articulated by National Research Council, 2012; NGSS Lead States, 2013; National Science and Technology Council, 2018). Indeed, the Henderson Creek project primarily explored the potential to cultivate domain-specific knowledge and skills pertaining to a distinct aspect of the creek's unique ecosystem, which could benefit the entire community's collective science literacy (Roth and Lee, 2004). Furthermore, child participation in a community project imposes additional requisites on formal science education, necessitating the organization of the project if not already in place, alignment with established science curriculum standards, and suitability for children within a specific age group. Lastly, akin to most research on child participation, this project predominantly relies on qualitative data, which can pose challenges in drawing comparisons with mainstream science education research and making broad generalizations.

The objective of this study is to take a small step forward by assessing a domain-general cognitive skill, namely relational thinking, within the context of science learning in a participatory environment, besides at an early age. The rationale for this choice is threefold: (1) Relational thinking is intricately intertwined with science (Dunbar and Klahr, 2012) and aids secondary school students in comprehending complex causal-relational STEM concepts (Goldwater and Schalk, 2016; Gray and Holyoak, 2021). (2) It plays a pivotal role in facilitating science learning (Dumas, 2017) and serves as a fundamental mechanism that underpins case comparisons in education (Alfieri et al., 2013) by highlighting shared structural elements. This, in turn, fosters the ability to generalize and transfer knowledge across different domains (Richland and Simms, 2015). (3) The incorporation of analogies as an instructional practice has been shown to enhance knowledge and the ability to understand analogies in science (Alexander et al., 1989), distinguish relevant source analogs in mathematics (Richland and McDonough, 2010), facilitate learning of Le Chatelier's Principle in chemistry (Trey and Khan, 2008), and promote far-reaching knowledge transfer in biology (Emmons et al., 2018).

Moreover, since participatory science learning has been largely unexplored at earlier stages of education, the focus on relational thinking may help to fill this gap. At 4–5 years of age, children similarity matching move from a purely perceptual and object-oriented approach to a more structural and relational approach (Gentner, 1988; Goswami, 1996; Rattermann and Gentner, 1998). The so-called relational shift is deeply intertwined with knowledge that improves processing of objects, relations and relational structure (Brown, 1989; Vosniadou, 1989; Goswami, 1991; Gentner, 2010), emphasizes the contextual or culturally valid information processing strategy (Bulloch and Opfer, 2009; Carstensen et al., 2019) and depends on executive functions (Halford et al., 1998, 2002; Richland et al., 2006; Thibaut et al., 2010). Hence, if child participation enhances domain-specific knowledge and participatory science activities highlights relational structures and challenge executive functioning, it can be expected that relational thinking will generally improve.

2 Study objectives and hypothesis

The study aimed to investigate whether child participation in science could enhance relational thinking in children aged 3–5. Teachers were encouraged and supervised as they created a participatory learning environment within their routine science lessons, adhering to a prescribed curriculum. The hypothesis posited that child involvement in these standard science activities would expedite the development of relational thinking as a domain-general skill.

There are two main justifications for this hypothesis. First, children were anticipated to construct concepts related to weight, height, quantity, body parts, and the life cycle. These concepts heavily rely on comparisons with standards, attentiveness to transformations, and an understanding of the relationships between various elements. Consequently, they were expected to develop a deeper comprehension of concrete objects, their attributes, and the connections between them. This foundational knowledge serves as a prerequisite for what is known as the "relational shift" (Gentner, 1988; Goswami, 1996; Rattermann and Gentner, 1998). Furthermore, beyond the domain-specific knowledge acquired, these science activities were also designed to teach children to recognize and utilize relationships between objects. Previous research has demonstrated that paying attention to relationships fosters the development of a "relational mindset" in both children (Walker et al., 2018; Simms and Richland, 2019) and adults (Bliznashki and Kokinov, 2010; Vendetti et al., 2014), and it predicts overall improvement in relational thinking at least immediately following manipulation. Regular attention to relations, however, may establish habitual patterns of attention allocation, thus explaining cross-cultural differences in preschoolers' preferences for relations (Simms and Richland, 2019; Christie et al., 2020). Therefore, it was reasonable to anticipate a domain-general enhancement in relational thinking as a result of these science activities, beyond the specific content covered in the curriculum.

Secondly, child participation fosters exploratory behavior, leading to the identification of open questions and knowledge gaps associated with curiosity (Jirout, 2020). While children typically do not recognize and utilize relations before the age of four, engaging tasks with an element of amusement can elicit genuine curiosity (Gentner et al., 2021), prompting even 2-year-olds to move beyond object similarity and contemplate the relationships between objects in pairs (Walker and Gopnik, 2014). Moreover, if science learning places a strong emphasis on relationships and child participation heightens the inclination to employ relationships, as suggested by the qualitative studies mentioned earlier, then child participation in science may lead to a broader utilization of relationships in various contexts, perhaps due to a stable relational bias in attention allocation.

Additionally, relational thinking and, consequently, the relational shift were assessed in an underrepresented sample of Roma children from families with low socio-economic status (with an average family income of approximately 700 euros, as reported by local NGOs). This is significant because much of our understanding of relationship development patterns has been constructed based on Western samples, and this perspective has recently been questioned by cross-cultural data (Carstensen et al., 2019). This necessitates further systematic examination in other underrepresented samples and the refinement of existing theories (Christie et al., 2020). Therefore, another objective of this study was to evaluate the standard developmental trajectory of relational thinking within the Roma children community, serving as a baseline measure for relational thinking in this specific context.

3 Methods

3.1 Design

The study examined the impact of child participation through a longitudinal approach. One group of children, referred to as the Child Participation group (CP group), underwent testing twice: first before the introduction of the child participation approach in kindergarten, which took place in the middle of the 2021/2022 school year, and then after its implementation. To prepare for this approach, teachers received training in the theory of child participation as philosophy, values and knowledge about different levels of children's inclusion in the educational process and were presented with the method of participatory action research. Subsequently, they received bi-monthly supervision from February to May 2022 to reflect on their personal experience of implementing child participation in science (Supplementary material). The implementation period of the child participation in the regular natural science activities in the kindergarten groups lasted a total of 4 months.

In contrast, the Control group of children, referred to as the No Child Participation group (NoCP), underwent testing a year earlier, in April–May 2021, before the introduction of the child participation approach. It included children from the 1st and 2nd group of kindergartens. The younger kindergarten children formed the so-called NoCP1 group and the older ones the NoCP2 group. This distinction of the subgroups was made for a cross-sectional comparison designed to test for changes in relational thinking within the target sample. If the relational shift is observed within the target Roma community, it may explain the expected longitudinal change in relational thinking in the CP group. Furthermore, the NoCP2 group serves as an age control for the CP group's relational thinking 1 year later. A subgroup within the NoCP2 group was carefully matched for age and sex with the target CP group, serving as a cross-sectional standard for comparison. This subgroup will be denoted as the Matched No Child Participation group (NoCP Matched), and it will be employed as a control condition to evaluate the impact of child participation on relational thinking.

3.2 Participants

Children from the kindergartens operated by the Health and Social Development Foundation (HESED), situated in the Fakulteta neighborhood of Sofia, Bulgaria, participated in this study with written parental consent. These children all hail from the same closely-knit Roma community within the Fakulteta neighborhood. According to their assistant teachers, who also belong to the same community, it is rare for young children in this community to engage in any form of formal education, and organized learning activities, whether related to science or other subjects, are notably absent. At HESED kindergartens, children follow the state curriculum tailored to their respective age groups, which includes science education. Simultaneously, they receive instruction in the Bulgarian language and work on the development of specific fine motor skills and cognitive abilities as necessary. The overarching goal of the HESED Foundation is to ensure an equitable starting point for Roma children, enabling them to seamlessly integrate into the educational system and meet the state's educational requirements for their age.

The initial test was administered in April–May 2021, involving a total of 57 children. Among them, 36 children from grade 2 of the kindergarten transitioned to primary school in the end of the 2021/2022 school year, forming the control NoCP2 group. This group served as a baseline for assessing relational thinking in children from the same community, of the same age, and following the same science curriculum, all prior to the introduction of the child participation approach. A subset of these children comprised the NoCP2 Matched group, corresponding one-to-one in age with the children who participated in the participatory science learning. The remaining 21 children were followed longitudinally, and they constituted the CP group. However, due to different reasons, 6 of them did not take part in the second measurement in April–May 2022 (3 due to leaving kindergarten, 2 due to being abroad, and 1 due to absence). All kindergarten grade 1 children, including those in the CP group, plus the six children who did not participate in the final measurement and therefore dropped out of the CP group, constitute the NoCP1 group. Table 1 displays the mean age in months, age range, and gender distribution of children within each group and for each experimental condition.

3.3 Stimuli

A relational matching-to-sample task (RMTS) was utilized to assess relational thinking. In this task, each stimulus consisted of three pairs of object images, as described by Brady et al. (2008, 2013). One of these pairs served as the reference or standard for comparison and was presented at the top of the slide. The other two pairs served as alternative choices and were presented below the standard pair. Both choice alternatives were valid answers, with one choice based on the same relation as the standard, and the other choice based on the same objects as the standard but entering a different relation. To illustrate, if the standard pair featured two open

TABLE 1 Mean age in months, age range, and gender distribution of children within each group and for each condition (i.e., tests 1 and 2) in the study.

Group	Age at test 1 (2021)	Age at test 2 (2022)
CP (10 girls and 5 boys)	48 months (Min = 41, Max = 52)	59 months (Min = 54, Max = 64)
NoCP1 (14 girls and 7 boys)	47 months (Min = 40, Max = 52)	–
NoCP2 (21 girls and 15 boys)	58 months (Min = 53, Max = 64)	–
NoCP2 Matched (11 girls and 4 boys)	59 months (Min = 54, Max = 64)	–

purple books side by side, the relational match would involve two open green books, and the object match would include an open book and a closed purple book.

The set of RMTS stimuli consisted of 10 sets, each comprising a standard pair and its corresponding relational and object match (Figure 1). Both the objects and the semantic relationships that linked them were familiar to the children in the targeted Roma community and age group, as confirmed through pre-checks by their teachers and assistant teachers. The stimuli featured either food items (e.g., apple, biscuit, egg, carrot, juice, melon, and radish) or everyday objects (e.g., book, balloon, cup, iron, and towel). These objects were associated with various relations, including cut/whole, folded/crumpled, open/

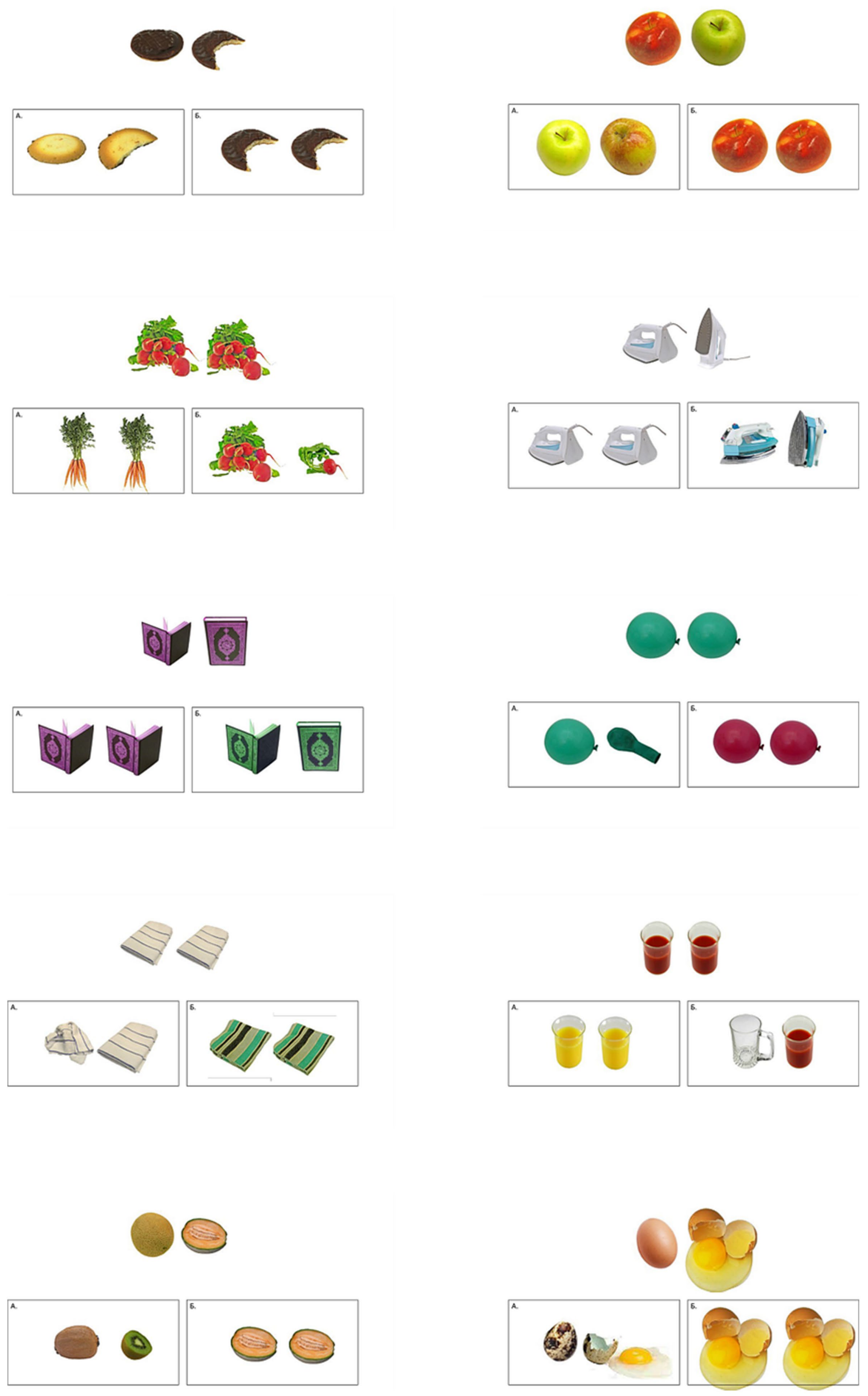

FIGURE 1
Example of RMTS stimulus set.

closed, inflated/collapsed, placed vertically/horizontally, full/empty, many/few, broken/whole, and one color/different color.

Each RMTS stimulus had two versions, depending on the relation depicted in the standard pair. For example, in the case of the book stimulus mentioned earlier, the SAME version featured a standard with two open books, while the DIFFERENT version had a standard with an open and a closed book. Consequently, the relational match for the SAME and DIFFERENT versions of the same stimulus containing identical objects differed. In the SAME version, the relational match for two open books would be two open books, while in the DIFFERENT version, the relational match for the open and closed books would be an open and a closed book. In both versions, the perceptual match consisted of the same objects as in the standard (i.e., the same books in the same color) but arranged in the wrong relation. Among the 10 RMTS stimuli, 5 featured a SAME relation in the standard pair, while the other 5 featured a DIFFERENT relation. The spatial position of the answer alternatives was counterbalanced across stimuli and participants.

For children who underwent preference testing twice within a year, they were tested with one version first and then with the other, with the order of testing versions balanced. As a result, each child encountered the same objects in the same configurations twice, but the target relation within the standard pair, and consequently the correct responses, differed between the two tests.

3.4 Procedure

Child participation in science was actively encouraged during group activities in kindergarten, following a predefined schedule aligned with the state-approved science curriculum. Meanwhile, individual assessments of relational thinking were conducted by HESED kindergarten psychologists. The study's procedures and stimuli received approval from the Departmental Research Ethics Committee. All children in the sample were approached for participation following explicit written consent from their parents.

The RMTS stimuli were presented sequentially on a computer screen, with psychologists recording the child's responses by hand. No feedback was provided during or after the test. Typically, the experimenter directed the child's attention to the standard pair at the top of each stimulus and posed questions in the following manner: "Which of these below (pointing to each pair one by one) is similar to the one above (pointing to the standard)?" or "Take a look at this (pointing to the standard or naming the objects, e.g., look at these books, towels, these cups)! Which of these two (pointing to the choice alternatives) is like the one above (indicating the standard)?" On average, each child required approximately 10 min to complete the task.

Child participation in science learning was ensured through a series of measures. Four months before the second RMTS test, a qualitative assessment was conducted to gauge the kindergarten teachers' implicit understanding and prior experiences related to child participation in science education. Following this assessment, the teachers and assistant teachers received training in action research, reflection, and various levels at which child participation could be integrated into the learning process. Throughout the implementation of child participation in science, teachers and assistant teachers received support through bi-monthly group supervision sessions held over 4 months. These sessions provided them with an opportunity to share their experiences, learn from one another, and discuss successful strategies for involving children in science education.

4 Results

4.1 The extent of child participation in science activities as perceived by teachers

As child participation in science had not been implemented at such a young age, teachers' implicit understanding of the approach, their shared experiences during the two-month supervisions were systematized, and their behavior during the 6 science activities was videotaped and analyzed (Mateeva et al., 2023). In short, the perspective of the educators aligned well with the concept of pedagogy of listening (Turnšek, 2016), which underscores the teacher's crucial role in listening to and responding to the needs and interests of the children. Children had the opportunity to choose materials, learn from each other, learn by imitation, discover by doing, discuss, participate in group decision making, etc. (Supplementary material). Also, the videotaped science activities showed significant progress over time in educators' attempts to stimulate children's inclusion and participation in the group. Therefore, teachers' pedagogical practices during regular science activities became significantly more inclusive and participatory, reflecting well their implicit understanding of children's participation in science at a given early age.

4.2 Base-level for relational choices with RMTS

The average number of relational choices was computed for each child in every condition. The mean proportion from all measurements before the introduction of child participation in kindergarten (i.e., the first RMTS test) was 0.3 (SD = 0.46). Generally, children from the targeted Roma community exhibited a preference for perceptual choices over relational ones in the RMTS, irrespective of their age group (i.e., 3–4 years and 4–5 years). The average proportion of relational choices was 0.31 for the NoCP1 group and 0.29 for the NoCP2 group. A chi-square test of independence was conducted to assess the relationship between the two sets of relational choices, and it was found to be not significant: $\chi^2(8, N = 57) = 12.005$, $p > 0.05$. Consequently, no evidence was found for a qualitative shift in relational thinking at this age, akin to the relational shift observed in Western samples (Gentner, 1988; Goswami and Brown, 1990; Gentner and Rattermann, 1991; Rattermann and Gentner, 1998).

4.3 Longitudinal analysis of relational choices

The relational choice proportion for the CP group in the second test (48%) was significantly higher than in the first test (29%). The Wilcoxon Signed Ranks Test revealed a significant difference between the two: $z = -2.285$, $p < 0.001$, $r = 0.42$. This increase in relational choices was not observed in the larger sample, as previously reported.

To explore whether the number of years in kindergarten (2 years) and age might explain this cognitive gain, cross-sectional analyses were conducted using age-matched controls.

4.4 Cross-sectional analyses of the relational choices

To assess the relationship between the CP and NoCP2 relational choices (48 and 29%, respectively), a chi-square test of independence was conducted. The relationship between the choices of the two groups was significant: $\chi^2(8, N = 51) = 16.518$, $p < 0.001$, $\varphi = 0.569$. Despite receiving similar educational experiences, including attending the same kindergarten and using the same curriculum, the children in these two groups were from the same community and of the same age. To further equalize the two groups, a subset of NoCP2 children was selected to match the ages of CP children in months at the time of the second RMTS test. Once again, the chi-square test of independence demonstrated a significant relationship between the proportion of relational choices for the CP group (48%) and the NoCP2matched group (22%), with an even larger effect size: $\chi^2(7, N = 30) = 18.133$, $p < 0.001$, $\varphi = 0.777$.

5 Discussion

The data presented supports the significance of participatory learning in science as a catalyst for relational thinking. Children who were encouraged to actively engage, voice their opinions, and explore science materials during regular kindergarten science activities demonstrated a heightened sensitivity to the relationships between everyday objects. Their shift in preference in the RMTS was nearly twofold compared to children of the same community, age, and kindergarten. This shift cannot be attributed to domain-specific knowledge (Gentner, 1988; Goswami and Brown, 1990), as RMTS stimuli do not directly relate to the science materials used in participatory science activities. Consequently, specific knowledge about the stimulus objects and their relationships was not developed.

Furthermore, the state science curriculum followed in kindergarten remained consistent across all children in the same age groups throughout the study. Therefore, the observed relational shift is more indicative of a domain-general transformation in relational choices, likely stemming from children's active involvement in science activities that necessitate an emphasis on understanding how objects are interconnected (for example heavier than, often means more than, but also may be related to stronger than, since stronger muscles may lift heavier objects), fostering their innate curiosity about the world around them. This participatory science learning environment has most likely shifted the allocation of attention from objects to the relationships between them, as cross-cultural evidence implies (Christie et al., 2020).

However, it is essential to recognize that child participation in science, as described by both teachers and assistant teachers, is a multifaceted and mutually reinforcing endeavor. It yields benefits beyond science literacy, encompassing emotional and social skill development, among others. Additionally, teachers in the observed Roma kindergartens employed child participation in science learning with remarkable flexibility and pragmatism, seamlessly integrating scientific concepts and skills into various contexts and activities. For example, teachers might incorporate discussions about nutrition during mealtime or encourage children to explore plant properties during outdoor playtime. As a result, drawing definitive conclusions about how participatory science learning impacts attitudinal choices necessitates further refinement and rigorous testing.

6 Conclusion

Based on the presented data, it is evident that child participation can serve as an effective means to expedite science learning by bolstering relational thinking as a domain-general cognitive skill, thereby fostering further advancement in science education. The observed shift in relational choices was not an explicit objective of participatory science learning; rather, its primary aim was to engage and stimulate young Roma children, encouraging their active involvement in regular science activities. Alongside the first-hand knowledge of science fostered in the current implementation of child participation in science, which extends children's scientific literacy and thus presumably enhances relational thinking (Brown, 1989; Vosniadou, 1989; Goswami, 1991; Gentner, 2010), there was also room for peer learning (Rogoff, 2003) and multiple unsupervised comparisons (Doumas et al., 2008; Christie and Gentner, 2010) that could further support the observed relational shift.

Furthermore, this study did not yield evidence of a relational shift within the Roma community. Consequently, relational similarity might not be the predominant cognitive strategy among the Roma group in focus. However, it is important to acknowledge the need for further research in this domain, given that the sample was small and the relational thinking in this cultural context has been explored for the first time, assessed through the RMTS, and that the proportion of relational choices, in general, remains quite low.

And finally, unlike other implementation attempts in education that rely on teacher training (Yoshikawa et al., 2015; Mendive et al., 2016), participatory learning in science improves children's behavior, not just teachers' skills, possibly because of its broader scope. It focuses on the learning environment, making learning more inclusive and participatory, and therefore receives as a given the benefits of the social situation, such as attention, engagement, participation, etc. Similarly, other basic cognitive skills, such as executive functions, have been found to develop better when stimulated by the social environment compared to targeted interventions (Diamond, 2012).

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by the Committee for Research Ethics of Department of Cognitive Science and Psychology, New Bulgarian University. The studies were conducted in accordance with the local legislation and institutional requirements.

Written informed consent for participation in this study was provided by the participants' legal guardians/next of kin.

Author contributions

PH: Writing – review & editing, Writing – original draft, Supervision, Project administration, Methodology, Formal analysis, Data curation, Conceptualization. NK: Writing – review & editing, Funding acquisition. AM: Writing – review & editing, Investigation.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/feduc.2024.1298337/full#supplementary-material

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