



Learning in pairs, thinking in shapes: A study on spatial reasoning in elementary school

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Article info	Abstract
Keywords: Elementary, Mathematics, spatial reasoning, power of two model	This study examines the effectiveness of the Power of Two learning model in improving fifth-grade students' spatial reasoning skills, specifically in understanding plane figures and composite areas. A quantitative approach was employed using an Interrupted Time Series Design, involving 29 students from a public elementary school. The instrument used was the VR-test (Visualization and Relation Test), designed to measure two components of spatial reasoning: spatial visualization and spatial relation. The test was administered in two phases: a pre-test before the intervention and a post-test afterward. The pre-test assessed students' initial ability to identify and calculate the area of shapes that form composite figures. After the Power of Two intervention, students showed an increase in their average post-test scores, indicating improved spatial reasoning. Statistical analysis using paired and independent-samples t-tests revealed significant differences between pre- and post-test results, confirming the intervention's effectiveness. The findings also demonstrated that both male and female students improved, although males slightly outperformed females in spatial visualization and spatial relations. Furthermore, the study highlights the pedagogical potential of peer collaboration and structured dialogue in developing students' spatial thinking. These findings provide empirical support for integrating cooperative learning models, such as the Power of Two, into elementary mathematics instruction.

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1. Introduction

Spatial reasoning is a cognitive ability that enables individuals to understand and process information about shapes, spaces, and the positions of objects, including mentally visualizing and rotating them (Leni et al., 2021). It involves imagining an object or location from various perspectives (Rahayu et al., 2022) and is closely related to one's capacity to interpret and manipulate visual and spatial information (Kurt et al., 2023). This includes sensitivity to color, shape, line, space, and the interrelationships among these elements, as well as the ability to accurately observe spatial visual objects and mentally transform them into other forms (Kurt et al., 2023). Spatial reasoning is regarded as an essential skill, as individuals with well-developed spatial reasoning can effectively solve real-life problems, such as navigation, computer-based tasks, and interpreting maps, all of which require spatial orientation (Manik & Zubainur, 2023; Maulana, 2021).

Spatial reasoning plays a vital role in several academic domains, particularly mathematics. Studies reveal that strong spatial reasoning is positively associated with improved mathematics performance, especially in geometry learning (Sudirman & Alghadari, 2020). Geometry is a key component of mathematics that significantly contributes to the development of spatial reasoning skills (Meyvita & Azizah, 2024). Learners with good spatial reasoning can estimate the relationships among geometric figures and anticipate changes in their shapes, particularly in real-world contexts (Leni et al., 2021). This skill enhances students' understanding of geometry, particularly in two-dimensional shapes. As geometry deals with abstract objects, solving problems in this domain requires well-developed spatial reasoning. Thus, spatial reasoning should be cultivated and strengthened during the learning process to help students comprehend geometry more deeply, not merely memorizing formulas, but solving problems visually and logically (K. Kurniawan, 2019; Pradana et al., 2020; Pradana & Sholikhah, 2023).

Theories from various experts identify multiple dimensions of spatial reasoning. Spatial reasoning highlights two key aspects: spatial visualization and spatial orientation (Destiani et al., 2023). On the other hand, spatial reasoning is categorized by spatial perception, mental rotation, and spatial visualization (Porat & Ceobanu, 2024). Furthermore, spatial reasoning comprises five components: spatial perception, spatial visualization, mental rotation, spatial relations, and spatial orientation (Pasaribu & Suratman, 2022). Numerous studies adopt three primary aspects: (1) spatial perception, referring to the understanding of shapes in space; (2) spatial visualization, involving the mental construction of spatial arrangements; and (3) mental rotation, referring to the ability to mentally rotate shapes (Harris, 2023; Supli & Yan, 2024). Additional views describe mental rotation as the ability to rotate geometric figures, spatial orientation as the recognition of changes in spatial figures, and spatial visualization as the identification of objects from multiple viewpoints (Manik & Zubainur, 2023; Pradana & Sholikhah, 2024).

Spatial reasoning is especially relevant in elementary mathematics education, particularly in geometry topics such as calculating the area of composite two-dimensional figures. Understanding area measurement demands precision and attention to detail (Salsabilah et al., 2023). Learning to calculate the area of composite shapes is an essential application of the area measurement strand of mathematics curricula, with direct relevance to daily life and occupational contexts, and it also lays the foundation for future mathematical ideas, such as surface area measurement and definite integral calculus (Lehmann, 2023). However, preliminary observations indicate that students struggle with solving area problems involving composite shapes. Students find it difficult to visualize and mentally decompose such figures. Challenges include difficulty forming accurate mental constructs, the need for precise measurements, and time-consuming calculations. Furthermore, numerous students fail to verify the correctness of

their solutions (As'ari & Kusaeri, 2024; Az Zahra & Hakim, 2022). For example, they often confuse squares with rectangles when combined, and while some can calculate individual areas, they struggle to integrate them into a single total (Salsabilah et al., 2023). Research consistently confirms that students face at least five key challenges in area measurement: conservation of area quantity, proper understanding of units, spatial structuring of figures, multiplicative composition, and differentiating area from perimeter (Lee et al., 2023). In particular, spatial visualization aligns closely with the nature of shape decomposition required for composite area tasks; yet when metric requirements are introduced, students become constrained by formulaic thinking rather than spatial processes (Harris et al., 2023).

Instructional approaches commonly focus on procedural tasks, with little emphasis on visualization or conceptual integration (Fauzi & Arisetyawan, 2020). Therefore, it is essential to enhance students' spatial reasoning so they can recognize, transform, and mentally represent geometric objects before producing physical representations (Dewi & Hakim, 2024). Spatial thinking remains an undervalued, under-recognized, and under-instructed feature of mathematics education despite playing a critical role in the learning, doing, and communicating of mathematics at the elementary and middle school levels (Hawes et al., 2023). A comprehensive review further reveals that spatial skills can predict mathematics performance across domains, with non-rotational spatial visualization being especially relevant for geometry tasks involving decomposition, reflections, and spatial structuring (Schenck & Nathan, 2024). Specifically, improving spatial visualization and spatial relations is critical. Spatial visualization refers to one's ability to mentally manipulate, rotate, or flip visually presented stimuli (Aini & Suryowati, 2022), while spatial relations involve recognizing positional relationships among objects in space (Teapon & Kusumah, 2023). Importantly, a study conducted with students from underprivileged Indonesian communities demonstrated that a spatialized mathematics intervention yielded significant improvements in both spatial visualization skills and mathematics performance, including transfer effects that varied across student ability levels (Winarti et al., 2024).

Prior studies have explored approaches to improving students' spatial reasoning. One used the Blended Discovery Learning model (Subhi et al., 2023), though it employed different reasoning components and was conducted during the pandemic, limiting its present-day relevance. Another study applied the Realistic Mathematics Education approach at the secondary level under a different curriculum (Balakrishnan et al., 2023). A spatial training intervention study using a pre-/post-test design found that training a range of spatial skills significantly improved students' performance on measurement and geometry items compared to a control group, though transfer to number and algebra items was not observed (Adams et al., 2023). A randomized controlled trial involving Grade 4 students produced large additive effects on both spatial skills and mathematical performance, demonstrating the superiority of contextually integrated approaches over isolated spatial training (Lowrie & Logan, 2023). Research comparing the Power of Two model with conventional instruction in learning triangles reveals several effectiveness (Ali & Usman, 2020), yet it was limited to a single geometric shape. The Power of Two model encourages both individual and paired problem-solving and fosters comparative analysis between two concepts or objects (Ardi et al., 2020). This model supports student collaboration in solving object-based problems, promoting the exchange of ideas and strategies (Mira, 2021). A meta-analysis found that cooperative learning produced a moderate-to-large positive effect on primary students' mathematics achievement, confirming its consistent instructional effectiveness across varied contexts (Talkhan et al., 2025). It integrates students' abilities to mentally visualize and understand the spatial relationships among geometric figures,

thus potentially improving learning outcomes (Wirajaya, 2019). The effectiveness of cooperative learning models in improving mathematical abilities has also been empirically supported at various educational levels, affirming the pedagogical potential of structured pair-based approaches in mathematics instruction (Tinungki et al., 2024). Collaborative problem-solving in mathematics has further been shown to promote diversified learning methods where hands-on practice, independent exploration, and peer exchanges become integral components of the learning process, moving beyond conventional receptive learning approaches (Cao, 2024).

This study aims to examine and analyze the impact of the Power of Two learning model on the enhancement of fifth-grade students' spatial reasoning. The primary focus is on two key components: spatial visualization and spatial relations, both essential for mastering composite shapes. The study also investigates how this combination of a collaborative model and digital media can help students overcome challenges in visualizing and integrating geometric components, thereby fostering deeper, more logical, and meaningful geometric understanding.

2. Literature review

2.1 Theoretical perspectives on spatial reasoning in geometry learning

Spatial reasoning is one of the essential skills that individuals must master in learning geometric concepts (Battista, 2017). This is because spatial reasoning refers to the ability to represent, transform, generate, and recall non-linguistic information (Peterson et al., 2020). Similarly, spatial reasoning is defined as the representation and use of objects and their relationships, which can be understood geometrically in both two and three dimensions (Bates et al., 2023). This definition underscores that the scope of spatial reasoning involves the use and manipulation of both two-dimensional and three-dimensional objects.

Based on a mathematical perspective, spatial reasoning plays a crucial role in encoding and decoding (Francis et al., 2016), as it involves spatial information. Furthermore, spatial reasoning involves recognizing and manipulating the properties of spatial objects and their relationships (Mulligan et al., 2017). Its scope encompasses the capacity to search for, orient, and visualize objects; navigate paths; decode graphical information; and use and construct diagrams. Therefore, spatial reasoning is strongly associated with success in mathematics.

Despite this broad consensus, the existing literature reveals a critical tension: while spatial reasoning is acknowledged as foundational to mathematics learning, it remains systematically under-instructed and under-assessed within formal curricula (Hawes et al., 2023; Schenck & Nathan, 2024). Most prior studies have examined spatial reasoning either as an isolated cognitive construct or in relation to advanced STEM outcomes, leaving its role in elementary geometry tasks relatively underexplored. This gap motivates the present study's focus on spatial reasoning within the context of plane figures and composite areas in fifth grade. Based on the foregoing discussion, spatial reasoning in this study is defined as the process of representing and using objects and their relationships in two- or three-dimensional space, encompassing both two- and three-dimensional geometric forms.

2.2 The role of spatial visualization in interpreting and transforming geometric objects

Spatial visualization is the process of manipulating information presented in a spatial format (Ramful et al., 2017). This process involves understanding and mentally transforming spatial forms. Additionally, spatial visualization may involve performing a sequence of mental transformations and maintaining temporary mental images during the information processing phase. Beyond mentally manipulating objects, spatial visualization also includes the ability to

comprehend imagined movements in three-dimensional space (Rabab'h & Veloo, 2015). Thus, the scope of spatial visualization is the process of manipulating objects based on spatial information.

There are several key characteristics associated with the process of spatial visualization. These include: (1) the processes and products of creating, interpreting, using, and reflecting upon images or diagrams for the purpose of representing and communicating information; and (2) the generation and development of previously unknown ideas and the advancement of understanding (Haciomeroglu, 2016). Spatial visualization activities include sketching the result of folding or unfolding a particular configuration, drawing the faces of three-dimensional figures in the form of two-dimensional shapes, identifying parallel or perpendicular lines on 3D objects, detecting symmetries in figures, and matching parts or segments of geometric shapes (Ramful et al., 2017).

Critically, while prior studies have demonstrated that spatial visualization training can improve students' mathematical performance (Harris et al., 2023; Lowrie & Logan, 2023), a closer examination reveals crucial limitations. Many such interventions have been conducted either in isolation from regular mathematics instruction or in secondary and post-secondary contexts (Adams et al., 2023), leaving it unclear whether similar gains can be achieved through cooperative instructional models embedded in elementary classroom practice. Furthermore, research has shown that students with weak spatial visualization skills struggle specifically to decompose composite shapes and integrate partial areas into a coherent whole (Harris et al., 2023), yet few studies have directly targeted this sub-skill within cooperative learning frameworks. This gap constitutes a primary rationale for the present study.

2.3 Spatial relations as a core component of spatial reasoning abilities

Spatial relations refer to an individual's ability to understand and perceive the positional relationships between objects within a space (Destiani et al., 2023). Spatial relations involve understanding the spatial arrangement and positioning of objects or their parts, as well as recognizing the interconnections among them. For instance, one must be able to identify the same object even when it is presented in different orientations (Sudirman & Alghadari, 2020). Spatial relations are the ability to interpret the position and direction of an object within a given space. Unlike spatial visualization, spatial relations emphasize rotating the entire object mentally (Fehringer, 2023).

Although both spatial visualization and spatial relations are conceptually distinct, the existing literature tends to treat them as interchangeable or addresses them independently of one another (Schenck & Nathan, 2024). Studies that simultaneously measure and compare improvement in both components within a single instructional intervention remain scarce. This is a notable gap, as the two components likely interact in composite area tasks: students must both mentally decompose shapes (spatial visualization) and understand how those decomposed parts relate positionally to one another (spatial relations). The present study addresses this gap by measuring both components using the VR-test, allowing for a more differentiated understanding of how cooperative learning influences each dimension of spatial reasoning.

2.4 Unlocking student potential through spatial reasoning in math classrooms

Numerous studies have investigated the impact of spatial reasoning on mathematics education and consistently demonstrate that it can enhance students' achievement in mathematics. For instance, training in spatial visualization and mental rotation designed in the form of instructional activities has been shown to improve students' mathematical performance

(Lowrie et al., 2020; Mix et al., 2016). Furthermore, spatial skills have also been developed to enhance teachers' competencies in the STEM fields (Mulligan et al., 2020). Research confirms that spatial reasoning is a strong predictor of success in STEM careers (Newcombe & Shipley, 2015) and also widely applied in the arts (Schoevers et al., 2019).

In educational activities, several studies have designed instructional approaches based on spatial reasoning. Model Eliciting activities with Cabri 3D were found to improve students' spatial reasoning and increase their enthusiasm for learning (Hartatiana et al., 2017). The Ten-Structure model, a strategy for teaching addition among elementary students, also engages spatial ability (Salmah et al., 2015). The Outdoor Learning Activity model, supported by mobile technologies, has been used to explore spatial orientation in geometry (Supli & Yan, 2024). Additionally, lesson study has shown that both content knowledge and spatial reasoning can be improved through collaborative teacher inquiry (Moss et al., 2015; Tepylo, 2017).

However, a critical synthesis of these studies reveals three recurring limitations. First, the majority of spatial reasoning interventions in elementary mathematics have relied on technology-enhanced tools (e.g., Cabri 3D, AR, mobile devices) or teacher-directed approaches, with limited attention to student-centered cooperative models as vehicles for spatial development (Dashti & Yateem, 2018; Hartatiana et al., 2017; Supli & Yan, 2024). Second, most intervention studies have been conducted outside Indonesian educational contexts, raising questions about the transferability of findings to local curriculum structures and classroom conditions. Third, and most significantly, no prior study has examined whether the Power of Two cooperative learning model can serve as a mechanism for developing spatial reasoning in the specific domain of composite area measurement. The present study directly addresses these three gaps.

2.4 The power of two

Table 1. Activities on the power of two model

Phases	Activities Involving Media
Problem Presentation	The teacher presents questions using images displayed through digital puzzle media
	Students are asked to independently assemble plane figure puzzles to form a complete image
	Students are challenged to mentally manipulate and reorganize shapes into new forms
	Students are asked to complete a map puzzle by paying attention to the distances between rooms
	Students demonstrate understanding of spatial relationships between shapes and calculate the total area of the combined shapes
Pair Discussion	The teacher forms groups of two students
Collaborative Thinking	Students, in pairs, re-discuss the assembled plane figure puzzles until they are accurate and precise
	Students revisit their answers through discussion to find new solutions and gain different perspectives
	Students, in pairs, re-discuss the map puzzle until it is accurate and appropriate
	Students analyze the images again, adjusting the positions and distances of the shapes
Presentation of Results	Each group is asked to present the results of their discussion
	Students are able to explain the constituent plane shapes
	Students are able to convey the calculated area of the analyzed map

The Power of Two is an activity that can enhance classroom teaching and learning by emphasizing the benefits of relationships (Ali & Usman, 2020). The Power of Two model is a small-group learning practice that fosters maximum collaboration and mastery of essential skills through peer-learning activities in which two members work together to achieve basic competencies (Mira, 2021). This model represents a form of cooperative learning that emphasizes synergistic teamwork among group members (K. Kurniawan, 2019). This learning strategy is implemented in pairs, allowing for more effective collaboration and communication. Moreover, the approach encourages students to be more actively involved in the learning process, as the activities are more engaging and require direct participation in understanding the material (D. Kurniawan et al., 2021). The Power of Two is a learning strategy that integrates two distinct lines of thought—stemming from diverse backgrounds or abilities—into a collaborative effort to achieve shared goals. Logically, the fusion of two individuals' perspectives creates a new, stronger force that optimizes learning success (Wirajaya, 2019). Hence, the Power of Two is a small-group learning strategy focusing on two members working together to achieve basic competencies. This model promotes collaboration and strengthens student relationships through intensive teamwork and better communication. Working in pairs makes students more active and engaged in the learning process, leading to greater interest and full participation. The goal of the Power of Two is to merge the strengths of two minds to create a new, more effective force that enhances learning outcomes and achieves shared goals more efficiently. The activity on the power-of-two model is presented in Table 1.

3. Method

3.1 Design research

The present study employs a quantitative research design. This approach emphasizes the use of numerical data, statistical techniques, and measurement processes to understand phenomena, evaluate relationships between variables, and test research hypotheses. Given these characteristics, the quantitative approach was selected because the collected data have interval-scale measurements, making it suitable for numerical analysis using statistical methods to quantify relationships, differences, or trends. More specifically, this study adopted a one-group pre-test–post-test design, in which a single group of participants was measured before and after receiving an instructional treatment, without a control or comparison group. This design was selected because the study was conducted in a naturalistic, intact classroom setting, where random assignment or inclusion of a parallel control class was not feasible without disrupting the school's regular academic schedule. The design is consistent with exploratory quantitative research in elementary education settings where ethical and logistical constraints prevent experimental manipulation across groups.

3.2 Participants

This study involved 29 fifth-grade students from a public elementary school in Madiun, East Java, Indonesia. Participants were selected using purposive sampling, based on the criterion that the class demonstrated consistent difficulties in solving problems related to the area of plane and composite figures, as confirmed through preliminary classroom observation and teacher consultation. These documented learning challenges indicate the need for a targeted instructional intervention addressing spatial reasoning skills.

All 29 students participated in the pre-test, the instructional intervention, and the post-test, with no attrition. The participants ranged in age from 10 to 11 years and consisted of 20 female

and 9 male students. They were representative of public elementary schools in semi-urban areas of East Java, coming from varied socioeconomic backgrounds. Most students had access to basic educational resources, but their mathematical proficiency was generally limited, as indicated by prior classroom assessments. These contextual characteristics provided a meaningful basis for implementing the Power of Two instructional treatment and observing its effects on spatial reasoning.

3.3 Instruments

The research instrument is the VR-test (Visualization and Relation Test), specifically developed to assess students' spatial reasoning skills in solving problems related to the area of a plane and composite figures (see Table 2). The VR test was administered twice: a pre-test before the instructional intervention and a post-test immediately after the intervention. The VR-test consisted of 20 multiple-choice items, each scored dichotomously (1 point for a correct answer, 0 for an incorrect one), yielding a maximum total score of 20. Items were constructed based on a test blueprint aligned with the fifth-grade curriculum indicators for calculating the area of geometric shapes. The items were designed to measure two key components of spatial reasoning: spatial visualization and spatial relation (see Table 2). To establish content validity, the instrument and its blueprint were reviewed by three experts in mathematics education and educational assessment. Their feedback was incorporated through systematic item revision, ensuring clarity, relevance, and alignment of each item with the intended indicators. The reliability of the VR-test was estimated using the Kuder-Richardson Formula 20 (KR-20), which is appropriate for dichotomously scored items. The reliability coefficient was $r = 0.84$, indicating high internal consistency and confirming the instrument's suitability for this study.

Table 2. Spatial reasoning indicators

Spatial Reasoning Aspects	Indicators
Spatial Visualization	Able to mentally imagine changes in a 2D figure when it is cut, combined, or rotated
	Able to visualize the final form of a composite shape after spatial manipulation
	Able to identify parts of a composite figure based on mental visualization outcomes
Spatial Relation	Able to determine the relative position of shapes (e.g., above-below, left-right, parallel, intersecting) in a two-dimensional space
	Able to understand the relationships of size, direction, and orientation between two or more geometric figures
	Able to connect geometric elements such as sides, angles, and areas between figures within a given configuration or layout

3.4 Procedure

The study was conducted over five weeks during the second semester of the academic year, comprising one pre-test session, eight instructional sessions (each lasting 70 minutes, twice per week), and one post-test session. This timeline was determined in coordination with the classroom teacher to align with the school's geometry unit on plane and composite figures. The procedural sequence was as follows. First, the researcher developed and validated the VR-test instrument prior to the study. Following school approval and parental and guardian consent, the pre-test was administered to all 29 students in a single 60-minute session to establish baseline scores on spatial visualization and spatial relations.

The instructional intervention subsequently commenced in the following week. The treatment was based on the Power of Two cooperative learning model, which structures learning activities in three sequential phases: (1) individual work, in which each student independently attempts geometry tasks involving the identification and calculation of composite areas; (2) paired discussion, in which two students share their individual solutions, compare reasoning strategies, and collaboratively construct a joint answer; and (3) whole-class reflection, in which selected pairs present their solutions and the teacher facilitates discussion connecting students' spatial reasoning processes to geometric concepts. Each session incorporated VR-test-aligned tasks specifically, activities requiring mental decomposition of composite figures, identification of spatial relationships between component shapes, and calculation of total area through additive or subtractive strategies. Instructional materials were developed by the researcher and reviewed by the classroom teacher prior to implementation. Upon completion of the eight instructional sessions, the post-test was administered using the same VR-test instrument under identical conditions to the pre-test. Scoring followed the same dichotomous rubric (1 = correct, 0 = incorrect).

3.5 Data analysis

The data analysis in the present study used quantitative statistical procedures. The pre-test and post-test scores obtained from the VR-test were first compiled and tabulated for each student. Descriptive statistics, including mean, standard deviation, minimum, and maximum scores, were calculated to provide an overview of the students' performance before and after the intervention. To determine whether there was a statistically significant change in students' spatial reasoning abilities, a series of inferential statistical tests was performed. The data were analyzed in multiple phases to observe trends over time and assess the effectiveness of the Power of Two learning model. Specifically, a paired-samples t-test was used to compare pre-test and post-test mean scores, examining whether the instructional intervention produced a significant improvement. The assumptions of normality and independence were checked prior to conducting the test.

4. Results

4.1 Profile of spatial reasoning

The present study aims to investigate the effect of the Power of Two learning model on spatial reasoning skills among fifth-grade elementary students. A quantitative one-group pre-test–post-test design was employed, and the primary instrument used was the VR-test, which assessed two dimensions of spatial reasoning: spatial visualization and spatial relation. A total of 29 students participated in both measurement points. The pre-test was conducted to establish baseline scores on students' ability to identify component shapes within composite figures and calculate their areas. The pre-test results yield a mean score of 71.38, indicating a moderate level of spatial reasoning prior to the intervention. Following the implementation of the Power of Two learning model, the post-test is administered using the same instrument. The post-test mean score increases to 77.07, representing a gain of approximately 5.69 points. This improvement is illustrated in Figure 1.

While this increase is noteworthy, it should be interpreted with appropriate caution. Given the absence of a control group and the relatively small sample size ($n = 29$), it is not possible to attribute this gain exclusively to the instructional intervention. Alternative explanations cannot be ruled out. Nonetheless, the consistent direction and statistical significance of the improvement

across both spatial reasoning dimensions provide preliminary evidence that the Power of Two model may support spatial reasoning development in this context. These findings are best understood as indicative rather than conclusive, and replication with a larger sample and a comparison group is warranted before generalizations are made.

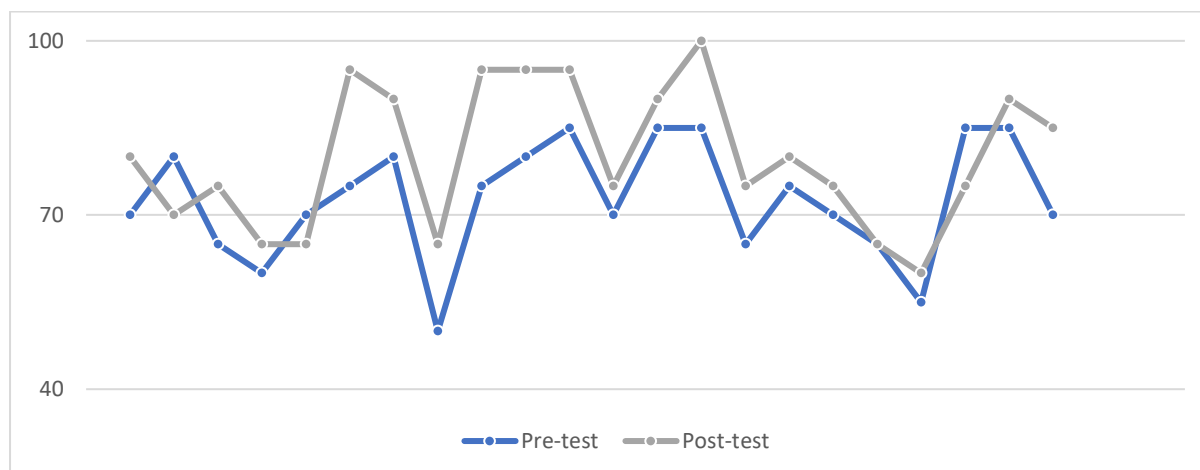


Figure 1. Comparison of pre-test and post-test scores on spatial reasoning

4.2 Performance across spatial visualization and spatial relation

To examine changes within each spatial reasoning dimension, paired-samples t-tests were conducted on the pre-test and post-test scores for spatial visualization and spatial relation separately. Prior to analysis, the normality of the score distributions was confirmed using the Shapiro-Wilk test ($p > .05$ for all groups), thereby satisfying the parametric assumption. The results indicate a statistically significant improvement in spatial visualization, with the mean score increasing from 74 in the pre-test to 81 in the post-test ($t = -6.02$, $p < .001$). Similarly, spatial relation scores improved from a mean of 62 to 72 ($t = -7.08$, $p < .001$). Both improvements were statistically significant, suggesting that students' performance on both dimensions of the VR-test increased following the instructional period.

To compare relative performance across the two dimensions following the intervention, an independent-samples t-test was conducted on the post-test scores for spatial visualization and spatial relation. The result was statistically significant ($t = 7.31$, $p < .001$), indicating that students scored meaningfully higher on spatial visualization than on spatial relation at post-test. This pattern underscores that, while both components indicate improvement, students found tasks involving mental manipulation of individual shapes more accessible than those requiring interpretation of positional and orientational relationships between multiple shapes.

These findings, however, should be moderated by this study's design limitations. The absence of a control group means it is not possible to determine with certainty whether the differential improvement across the two dimensions reflects a specific effect of the Power of Two model or a general learning trajectory that would have occurred regardless of the instructional approach. What can be stated with reasonable confidence within the constraints of a one-group design is that students who received the intervention reveal measurable gains in both dimensions, with relatively greater gains in spatial visualization. This observation may have practical implications for instructional design: future interventions should incorporate more

explicit tasks targeting spatial-relational skills to promote more balanced growth across both components of spatial reasoning.

4.3 Performance across gender

The analysis of gender-based differences in spatial reasoning explored whether male and female students demonstrated differential patterns of change following the instructional intervention. This investigation is reported descriptively and with appropriate caution, given that the sample included 9 male and 20 female students. A distribution that is notably unequal and limits the statistical reliability of between-group comparisons.

Paired-samples *t*-tests conducted within each gender group indicated statistically significant improvements for both male and female students following the intervention (see Table 3). For spatial visualization, male students' mean scores increase from 34.2 to 39.6 ($t = -4.98$, $p < .001$), while female students' scores increase from 32.7 to 36.8 ($t = -5.11$, $p < .001$). For spatial relation, male students improve from 33.8 to 38.4 ($t = -5.31$, $p < .001$), and female students improve from 33.3 to 37.2 ($t = -5.78$, $p < .001$). These within-group results underscore that the students of both genders show positive change following the instructional period, consistent with the overall improvement observed at the class level. Independent-samples *t*-tests were subsequently conducted to compare post-test scores between male and female students. The results indicate that male students score somewhat higher than female students on both spatial visualization ($t = 2.09$, $p < .05$) and spatial relation ($t = 2.01$, $p < .05$) at post-test. Although these differences reach conventional levels of statistical significance, several essential caveats must be acknowledged before drawing substantive conclusions.

Table 3. Spatial reasoning across gender

Data	<i>t</i>	<i>p</i>
Spatial visualization –male (pre-post)	-4.98	< .001
Spatial Visualization –female (pre-post)	-5.11	<.001
Spatial Relation – male (pre-post)	-5.31	< .001
Spatial Relation – female (pre-post)	-5.78	< .001
Spatial visualization – male vs female	2.09	< .05
Spatial relation – male vs female	2.01	< .05

First, the pronounced imbalance in group sizes reduces the statistical power and reliability of between-group comparisons. With only 9 male participants, the male group's mean is highly sensitive to individual scores, and the observed gender difference may not reflect broader population-level patterns. Second, the effect sizes associated with these between-group differences were small, suggesting that the gender gap is of limited practical significance. Third, the design of this study did not control for pre-existing gender differences in spatial reasoning; accordingly, it is not clear whether the observed post-test differences reflect a differential effect of the intervention itself or pre-existing ability differences. These limitations imply that the reported gender findings should be treated as exploratory rather than confirmatory evidence of gender-based differences in spatial reasoning outcomes.

With these caveats in mind, the finding that male students scored marginally higher than female students at post-test is broadly consistent with prior literature reporting small male advantages in specific spatial tasks, particularly those involving mental rotation and positional reasoning. However, it is equally essential to emphasize that within-group improvements for

female students were substantial and statistically significant across both spatial dimensions, indicating that the Power of Two model had a meaningful positive effect on female students' spatial reasoning. Future research with more balanced gender samples and a control group would be necessary to draw firmer conclusions about the differential effectiveness of this instructional approach across gender groups.

5. Discussion

This study examines the effectiveness of the Power of Two learning model in enhancing fifth-grade students' spatial reasoning abilities, particularly in the topic of plane shapes and composite area. The results reveal a statistically significant improvement in students' spatial reasoning skills, as reflected by the increase in average VR-test scores from pre-test to post-test. While this improvement is encouraging, it should be interpreted cautiously given the one-group pre-test–post-test design and the small sample size. The discussion below focuses on what this study contributes specifically to the existing literature, rather than simply confirming the broad effectiveness of cooperative learning.

The specific contribution of the present study lies at the intersection of three elements that, to the authors' knowledge, have not previously been examined in combination: (1) the Power of Two cooperative learning model, (2) the domain of composite area measurement in elementary geometry, and (3) the simultaneous assessment of two discrete spatial reasoning components — spatial visualization and spatial relation — using a purpose-built instrument (VR-test). Prior research on cooperative learning in mathematics has demonstrated general benefits for achievement (Talkhan et al., 2025) and prior research on spatial reasoning interventions has demonstrated gains in geometry performance (Adams et al., 2023; Winarti et al., 2024). However, these bodies of work have not converged on how a peer-dialogue-based cooperative model operates specifically through spatial visualization and spatial relations as separable mechanisms in composite area tasks. The present study provides preliminary evidence addressing that gap, and this specificity constitutes its primary scholarly contribution.

The Power of Two model, originally conceptualized as a cooperative learning strategy, emphasizes structured partner discussion and mutual engagement in problem-solving. Its foundation lies in fostering collaborative dialogue in which students share individual perspectives, justify their reasoning, and critically evaluate their partners' solutions (Ardi et al., 2020). Within the domain of composite area, such dialogic interaction is particularly well-suited. Learning to calculate the area of composite shapes is recognized as an essential application of area measurement, with the decomposition-and-recomposing heuristic applicable across domains of mathematics, including geometric reasoning and computational thinking (Lehmann, 2023). The decomposition phase of composite area tasks directly activates spatial visualization, as students must mentally manipulate two-dimensional figures (Harris et al., 2023), while the recomposing and relational phases activate spatial relation, requiring students to reason about the positional and orientational relationships between component shapes (Schenck & Nathan, 2024). The Power of Two structure creates natural opportunities for both components to surface and be discussed explicitly. Research on peer interaction in pair-based collaborative problem-solving confirms that when students discuss strategies together, group members can encourage and support one another, leading to improved performance (An & Zhang, 2024). This alignment between the model's pedagogical design and the cognitive demands of composite-area tasks distinguishes the present study from prior work on either cooperative learning or spatial reasoning in isolation.

The finding that spatial visualization improved more substantially than spatial relations following the intervention is theoretically meaningful and adds specificity to this contribution. It underscores that the paired discussion format of the Power of Two model may more readily scaffold the visualization component than the relational component, which requires more abstract reasoning about orientation, direction, and positional configuration. Classroom-based spatial reasoning interventions delivered within structured pedagogical frameworks have consistently demonstrated that children in experimental classes can outperform controls on spatial reasoning following the program, though gains tend to be stronger in object-level manipulation than in positional-relational tasks (Lowrie et al., 2018). This differential pattern has not previously been reported in the context of the Power of Two model, and constitutes a nuanced finding that contributes to the spatial reasoning literature. Spatial thinking remains an under-instructed feature of mathematics education despite its critical role in learning and communicating mathematics at the elementary level, and that intentional instructional design is needed to target different spatial components distinctly (Pradana et al., 2020; Pradana & Sholikhah, 2023). The present findings echo this argument: cooperative learning designs, while broadly beneficial, may not equally develop all components of spatial reasoning, and targeted supplementary tasks focused on spatial relations may be needed to complement the general paired-discussion format.

The research findings are consistent with prior research that underscores the potential of the Power of Two model in fostering mathematical understanding. Students who engaged in pair-based discussions demonstrated better performance in solving spatial geometry problems compared to those who worked individually (Ardi et al., 2020) and peer collaboration has been shown to help students refine their reasoning and visualize geometric relations more accurately (Sugandi & Kurniawan, 2018). In the context of collaborative mathematics problem solving, pair-based tasks that incorporate geometric drawing and area calculation have been shown to produce richer problem-solving discourse and more thorough articulation of spatial reasoning strategies than individual tasks (Liu & Wei, 2024). These studies support the general premise that learning becomes more meaningful when students articulate their thinking and respond to alternative viewpoints. The present study extends this line of evidence by specifying which dimensions of spatial reasoning benefit from such articulation.

Throughout the learning intervention, students demonstrated notable enthusiasm and active engagement. Following independent problem-solving, the partner discussion phase allowed students to exchange different strategies for decomposing and calculating composite areas (Nilsen & Teig, 2024). In many instances, students identified more efficient decomposition approaches as a result of peer input, and these moments of shared insight contributed not only to improved accuracy on VR-test items but also to greater engagement with the spatial demands of the tasks (Rusdiyawanti et al., 2021). This behavioral observation aligns with evidence from spatialized mathematics interventions showing that students can achieve significant improvements in both spatial visualization skills and broader mathematics performance when spatial reasoning is deliberately embedded in instructional design (Winarti et al., 2024). Furthermore, a comprehensive review of the spatial-mathematics relationship confirms that engaging with spatial properties and relations drives students' understanding and concept development, and that the relationship between spatial ability and mathematics is not simply correlational but can be leveraged causally through well-designed instruction (Nathan, 2024). This is consistent with the theoretical claim that spatial reasoning can be developed through intentional instruction and interactive learning experiences (Lin et al., 2024; Pangestu & Setyaningrum, 2020), and lends theoretical support to the quantitative findings.

Regarding gender differences, both male and female students reveal significant within-group improvements following the intervention, which is the more substantive finding from an instructional perspective. The marginal male advantage observed at post-test on both spatial dimensions is interpreted cautiously, given the pronounced imbalance in group sizes (9 males vs. 20 females) and the small effect sizes associated with between-group comparisons. A meta-analytic review of sex differences in mathematics across content areas, grade levels, and geographic regions confirms that male advantages in spatial-related mathematics domains such as geometry tend to be small at the elementary level and are moderated by content type, instructional context, and socio-cultural factors (Giofrè et al., 2020). Notably, research combining equity perspectives with spatial reasoning demonstrates that gender gaps in mathematics related to spatial skills are not fixed and can be reduced through targeted instructional programs, underscoring that the design of spatial learning activities has implications for equity as well as achievement (Ramful et al., 2017). Future research with more balanced gender samples and a control group would therefore be needed to draw firmer conclusions about the differential effectiveness of the Power of Two model across gender groups. What can be stated with confidence within the constraints of the present design is that the intervention produced consistent, statistically significant gains for both male and female students, indicating that the model holds broad instructional promise regardless of gender.

It is crucial to reiterate, however, that the improvements observed in this study cannot be attributed exclusively to the Power of Two model. The absence of a control group implies that concurrent instructional exposure, maturation, and test familiarity remain plausible contributing factors. Spatial training interventions demonstrate domain-specific transfer effects, elucidating that the particular content context in which spatial instruction is embedded plays a critical role in determining which mathematical sub-skills improve. The contribution of the present study is therefore best understood as providing domain-specific, instrument-sensitive preliminary evidence that the Power of Two model yields measurable gains in both spatial visualization and spatial relation, with a stronger effect on the former. This specificity aligns with the call in the literature for researchers to move beyond general spatial-mathematics correlations toward identifying how specific spatial skills can be enacted in practice within content-specific instructional designs (Winarti et al., 2024). Future studies employing quasi-experimental designs with control groups, larger, more gender-balanced samples, and extended intervention periods are needed to build on these preliminary findings and establish more definitive evidence of the pedagogical effectiveness of the Power of Two model in elementary spatial geometry education.

The development of spatial reasoning involves various processes, including mental rotation, spatial visualization, and spatial orientation (Harris, 2023; Hasanah et al., 2024; Pradana & Sholikhah, 2023). Students demonstrated growth across these dimensions, with particular progress in spatial visualization, the ability to mentally transform and manipulate two-dimensional representations in this study. The Power of Two model supported this development by giving students the space to test their mental images against peer explanations and receive immediate feedback through verbal clarification and visual comparison (Pangestuti et al., 2021).

Another essential aspect of the model's effectiveness is its ability to accommodate individual differences. Unlike linear instructional approaches such as the Van Hiele model, which requires students to progress through hierarchical levels of geometric understanding (Battista, 2017), the Power of Two model adopts a more flexible and student-centered orientation. Flexibility is crucial, especially in elementary education, where cognitive development varies widely among students (Citra et al., 2021). Students who initially struggled

with complex visual tasks benefited from peer scaffolding and were able to catch up through sustained interaction in this study.

Moreover, the Power of Two model aligns well with constructivist principles of learning. Students construct their understanding through dialogue, reflection, and social negotiation. The act of verbalizing spatial strategies, whether explaining a rotated figure, identifying a congruent shape, or estimating area, enhances metacognition and deepens learning (Francis et al., 2016). In our observations, students began to employ more precise language and conceptual representations after repeated partner discussions, indicating a consolidation of spatial concepts.

In terms of learning outcomes, statistical analyses reveal a significant difference between students' pre-test and post-test scores, confirming the model's impact. This aligns with other experimental studies that have shown the value of cooperative learning in improving mathematical thinking and spatial cognition (Bates et al., 2023; Slavin, 2015). Additionally, the model appeared to support both high-achieving and lower-achieving students. While high performers had the opportunity to reinforce and clarify their understanding by teaching their peers, lower performers gained new insights and confidence through guided support and exposure to effective problem-solving methods (Rahmawati et al., 2020).

Another key dimension worth noting is the development of visual, verbal, and symbolic representations during the intervention. Spatial reasoning is inherently multimodal. It relies not only on mental images but also on students' ability to express those images in language and symbols. The Power of Two model created space for students to articulate their thinking in all three modes. For example, numerous students drew diagrams to support their verbal explanations, while others used numerical expressions to represent geometric relationships. This multimodal expression is vital for mathematical communication and problem-solving (An & Zhang, 2024; Weisblatt et al., 2019). Furthermore, the model helped build positive attitudes toward mathematics. Several students reported enjoying the learning experience and feeling more confident in their abilities. Such affective factors are crucial, especially in geometry, where students often experience anxiety or disengagement (Pangestuti et al., 2021). The opportunity to work with peers, make mistakes without judgment, and receive real-time support contributed to a more inclusive and supportive classroom environment. It is also crucial to highlight that spatial reasoning is a strong predictor of success in STEM fields (Yüksel, 2017). As such, fostering spatial thinking at an early age has long-term educational implications. This study contributes to that effort by offering empirical evidence that spatial reasoning can be effectively cultivated in elementary classrooms through collaborative instructional approaches. The success of the Power of Two model underscores the need for schools to integrate more structured peer-based activities into their geometry curriculum.

The research findings are further supported by a growing body of evidence from elementary mathematics education research emphasizing the role of intentional instructional design in fostering both spatial and mathematical competencies. Geometry learning at the elementary level requires instructional approaches that make abstract spatial concepts accessible through concrete and contextually meaningful experiences, as demonstrated by the development of RME-based geometry teaching materials that significantly improved students' mathematical communication skills (Marlini et al., 2025). The integration of visualization tools in geometry instruction has similarly been shown to produce substantial gains in students' mathematical reasoning ability (Aflia et al., 2020; Loliyana et al., 2023). These findings underscore the theoretical claim advanced in the present study that spatial visualization, as a distinct cognitive component, is particularly responsive to structured instructional intervention. Beyond individual

tool use, the broader architecture of cooperative learning also plays a constitutive role in mathematics achievement; peer interaction within creative and collaborative learning structures creates conditions in which students negotiate spatial strategies, expose misconceptions, and construct more robust geometric understanding through dialogue (Ananda et al., 2023; Faot, 2021). In the domain of geometry specifically, technology-mediated learning environments have further illustrated how contextually embedded instructional design supports conceptual understanding of spatial relationships in elementary classrooms, as evidenced by the development of Desmos-integrated ethnomathematics materials for grade IV geometry instruction that demonstrated strong validity and effectiveness in improving students' geometric conceptualization (Laily et al., 2020; Simorangkir et al., 2025). At the level of pedagogical approach, project-based collaborative learning has consistently been shown to cultivate the kind of disciplined, cooperative problem-solving discourse that underpins spatial reasoning development, with findings indicating that structured pair and group tasks in science education significantly enhanced students' collaborative skills and deepened their engagement with content-specific reasoning processes (Anggriani et al., 2024; Naibaho et al., 2023; Sari et al., 2021). Taken together, these studies converge on the conclusion that the effectiveness of any cooperative learning model in developing spatial reasoning depends on deliberate instructional alignment among the model's pedagogical structure, the cognitive demands of the target content, and the quality of peer interaction the learning environment affords.

Lastly, it is worth noting the practical aspects of implementation. The Power of Two model does not require sophisticated technology or materials. Its core strength lies in its structure, alternating between individual thought and partner discussion. This makes it highly adaptable to diverse classroom contexts. However, its success depends on careful teacher facilitation. Teachers must define clear roles, monitor interactions, and provide scaffolding when necessary to ensure both partners are equally engaged and that misconceptions are addressed in a timely manner.

6. Conclusion and implications

The present study investigates the effectiveness of the Power of Two learning model in enhancing fifth-grade students' spatial reasoning skills, particularly in solving problems related to plane figures and composite areas. The results indicate a statistically significant increase in mean VR-test scores from pre-test to post-test, with improvements observed in both spatial visualization and spatial relation components. These findings provide preliminary evidence that the Power of Two model can support the development of spatial reasoning in elementary geometry, particularly in composite-area tasks. However, given the one-group pre-test-post-test design and the absence of a control group, these conclusions are offered as indicative rather than definitive, and should not be interpreted as establishing causal effectiveness of the model in isolation from other instructional factors. The model's collaborative structure allowed students to engage in meaningful peer discussions, compare and evaluate various problem-solving strategies, and develop a deeper conceptual understanding of geometric decomposition and area calculation. The differential improvement between the two spatial components underscores that the paired discussion format more readily scaffolds object-level mental manipulation than positional-relational reasoning. This finding implies that while the Power of Two model broadly supports spatial thinking development, additional instructional tasks specifically targeting spatial relations may be needed to achieve more balanced improvement across both components.

Regarding gender, both male and female students demonstrated statistically significant within-group improvements in spatial visualization and spatial relations following the intervention, indicating that the Power of Two model supported spatial reasoning development for students of both genders. However, the between-group comparison at post-test reveals that male students scored marginally higher than female students on both spatial visualization and spatial relations. These gender differences were small in magnitude and should be interpreted with considerable caution due to the pronounced imbalance in group sizes. It is crucial to note that no claim is made here that female students outperformed male students on any dimension, as such a claim would be inconsistent with the data. The overall pattern underscores that the model benefited both gender groups, with male students showing slightly higher post-test scores, though this requires replication with more balanced samples before substantive conclusions can be drawn.

Overall, the results reinforce the importance of social interaction and cooperative learning in fostering spatial thinking and mathematical reasoning at the primary school level. The study contributes a specific, previously unexamined empirical case: the application of the Power of Two model to composite-area problems, evaluated using differentiated spatial-reasoning indicators. This specificity represents the study's primary contribution to the mathematics education literature.

7. Limitation

As the study yielded promising preliminary results, several limitations must be acknowledged transparently. First, the research was conducted with a small sample from a single school in Madiun, which substantially limits the generalizability of the findings to other student populations, school contexts, or regional settings. Second, the one-group pre-test–post-test design lacks a control or comparison group; hence, observed improvements cannot be attributed exclusively to the Power of Two model. Alternative explanations cannot be ruled out. Third, the gender subgroup analysis was constrained by a pronounced imbalance between male and female participants, reducing the statistical reliability and interpretive value of between-group gender comparisons. Fourth, the intervention's duration was relatively short, limiting any evaluation of sustained or long-term effects on students' spatial reasoning development. Fifth, the study relied solely on a paper-based multiple-choice instrument (VR-test), without incorporating complementary data sources such as process-level observation, think-aloud protocols, or digital tools, which could provide more nuanced insights into students' spatial thinking processes during collaborative tasks.

Future research should address the limitations of the present study by extending the methods and context. First, studies employing quasi-experimental or experimental designs with a matched control group are necessary to establish more defensible causal claims about the effectiveness of the Power of Two model on spatial reasoning development. Second, replication studies with larger, more diverse samples would strengthen the generalizability of the findings. Third, future investigations should ensure more balanced gender group compositions to enable reliable examination of potential differential effects across genders. Fourth, extending the intervention beyond five weeks and incorporating delayed post-test measures would allow researchers to assess whether improvements in spatial reasoning are sustained over time.

Beyond these methodological improvements, future research could explore integrating technology-enhanced learning tools into the Power of Two model to provide richer spatial manipulation experiences and more sensitive measurement of students' reasoning processes.

Process-level data collection approaches, including think-aloud protocols, video analysis of paired discussions, and digital interaction logs, would shed light on the mechanisms through which peer dialogue supports or hinders the development of spatial visualization and spatial relations specifically. Additionally, exploring the application of the Power of Two model to other domains of mathematics beyond geometry could broaden understanding of its instructional applicability. Lastly, professional development programs should be designed and evaluated to support teachers in effectively implementing the Power of Two model, with particular attention to how teachers can explicitly scaffold spatial-relations tasks within paired-discussion formats to address the differential gains observed in this study.

Declaration and Statement

CRedit Authorship Contribution Statement

Lingga Nico Pradana: Conceptualization, Methodology, Formal analysis, Data curation, Writing – original draft, Writing – review & editing. Octarina Hidayatus Sholikhah: Methodology, Resources, Project administration, Investigation, Writing – review & editing. Joel L. Alvarez: Supervision, Validation, Formal analysis, Data curation, Funding acquisition, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

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This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors. The study was conducted independently by the authors, who bear the entire cost of the research.

Data Availability Statement

The data that support the research findings are available from the corresponding author upon reasonable request. Because the data include human participant information, they are not publicly available to protect participant privacy.

Ethical Declaration

This study involved human participants, namely fifth-grade elementary school students. The research was conducted in accordance with the principles outlined in the Declaration of Helsinki. Permission to conduct the study was granted by the principal of the participating elementary school. Because the participants were minors, the parents or legal guardians were fully informed about the study's purpose, procedures, data confidentiality, and the right to withdraw at any time without consequence before consent was given. The students were likewise informed in age-appropriate terms and were free to decline or discontinue participation at any point. The collected data were used solely for academic research and handled in strict confidence.

Informed Consent Statement

Written informed consent was obtained from the parents or legal guardians of all participating fifth-grade students prior to data collection, and verbal assent was obtained from the students themselves. Consent also covered the publication of the anonymised data presented in this article. No identifying information about any participant is reported.

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Declaration of Generative AI and AI-Assisted Technologies

Portions of this manuscript were drafted and edited using Claude (Anthropic). The authors used this tool to improve grammar, clarity, and the manuscript's overall coherence. All content generated by the AI was thoroughly reviewed, edited, and validated by the authors, who take full responsibility for the accuracy, integrity, and final content of this manuscript. No AI tool was used in the data collection, analysis, or interpretation of the research findings.

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