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Multisensory-Enriched Realistic Mathematics Education (RME) and Sixth-Grade Students' Conceptual Understanding and Mathematical Disposition

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Abstract
Indonesian elementary students' mathematical literacy remains below the OECD average. This study examined the implementation of Multisensory-Enriched Realistic Mathematics Education (ME-RME) for cubes and cuboids and compared students' conceptual understanding and mathematical disposition with conventional instruction. An exploratory sequential mixed-methods design was conducted at a public elementary school in Bekasi Regency, West Java. The qualitative phase involved structured observations of 35 sixth-grade students over four lessons and semi-structured interviews with 33 students; findings informed refinement of the lessons and instruments. The quantitative phase used a non-equivalent pretest–posttest quasi-experiment involving an experimental class (n = 35) and a control class (n = 35), each taught by the same teacher over four 70-minute lessons. Conceptual understanding was assessed through an essay test and mathematical disposition through a Likert-scale questionnaire. Analyses included ANCOVA, MANOVA, and Bonferroni-corrected follow-ups. Groups did not differ significantly at pretest, $t(68) = 1.32$, $p = .192$. At posttest, the experimental group outperformed the control group in conceptual understanding ($M = 90.69$, $SD = 5.85$ vs. $M = 68.46$, $SD = 7.47$; $t(68) = 13.86$, $p < .001$; Hedges' $g = 3.28$) and disposition ($M = 119.05$, $SD = 9.41$ vs. $M = 102.05$, $SD = 10.79$; $g = 1.66$). MANOVA was significant, Wilks' $\Lambda = .249$, $F(2, 67) = 100.80$, $p < .001$. ME-RME was associated with higher conceptual understanding and more positive mathematical disposition, although the short intervention, single-school setting, and non-random allocation limit generalizability.

Keywords*:* Conceptual Understanding; Mathematical Disposition; Multisensory Learning; Realistic Mathematics Education; Elementary Mathematics

INTRODUCTION

Education plays a vital role in producing high-quality human resources who are capable of adapting to the changing times. Within Indonesia's education system, mathematics is one of the core subjects, functioning to develop logical, analytical, systematic, and critical thinking skills. Nevertheless, the quality of mathematics education in Indonesia today still faces considerable challenges. Based on the results of the Programme for International Student Assessment (PISA) 2022, the mathematical literacy scores of Indonesian students remain far below the average of OECD countries (OECD, 2023). This achievement indicates a fundamental weakness in students' ability to understand and apply mathematical concepts to solve problems in real-life contexts. This phenomenon serves as a strong signal that the mathematics learning process, particularly at the elementary school level, has not yet run optimally in building a solid foundation of numeracy and conceptual understanding from an early age. Recent classroom research likewise emphasizes the importance of contextual mathematical tasks and carefully connected representations for making abstract ideas accessible (Fauzan et al., 2024; Netriwati et al., 2025; Utami et al., 2025).

Limited conceptual understanding is often rooted in conventional learning practices that

are overly abstract and focused on memorizing formulas without meaning. As a result, students may struggle to grasp the meaning of the material, hindering their cognitive and affective development (Netriwati et al., 2025; Bognar et al., 2025). Mathematics learning involves two closely related aspects: conceptual understanding (the cognitive domain) and mathematical disposition (the affective domain). Conceptual understanding ensures that students do not merely perform mechanical calculations but also understand the mathematical structures underlying them. Mathematical disposition, which includes self-confidence, curiosity, persistence, and a positive appreciation of mathematics, is important for students' long-term learning resilience (Febriyani et al., 2022; Soesanto & Dirgantoro, 2025). However, this affective aspect is often overlooked in the classroom, potentially contributing to mathematics anxiety and low learning motivation (Ampadu & Anokye-Poku, 2022; Nugraha & Samsudin, 2024). Studies of productive disposition also suggest that opportunities to explain ideas and experience success in authentic mathematical tasks may contribute to learners' confidence and persistence, although such outcomes depend on the learning context (Chua, 2021; Muhammad et al., 2025).

This research was conducted in a public elementary school in Bekasi Regency, West Java. Preliminary data showed that the average score for geometry on the previous semester's summative assessment was very low, with the class average below 70; that 60% of sixth-grade students had not reached the school's minimum mastery criteria (KKM); that the school's Education Report Card (*Rapor Pendidikan*) numeracy indicator was also low; and that teachers reported difficulties in teaching mathematics, particularly topics related to solid geometry. Both classes averaged below 60 on a 0–100 scale of conceptual understanding, and teachers reported that solid geometry had previously been taught through the memorization of formulas rather than through constructing and examining physical models. The problem addressed here, therefore, is not "Indonesia's mathematical achievement" in the abstract, but the specific difficulties this group of students experienced in moving from the physical properties of cubes and cuboids to their symbolic representation.

To address the problems identified above, an instructional approach is required that is contextual, engaging, and student-centred. Realistic Mathematics Education (RME) meets this requirement: it holds that mathematics must be connected to reality and treated as a human activity rather than as a finished product to be transmitted (Anjarwati et al., 2025; Do et al., 2021; Fauzan et al., 2024; Mutaqin et al., 2021). At the primary level, however, RME's level principle the progressive elevation of informal, context-bound strategies toward formal mathematics presupposes a sequence of increasingly schematic representational forms, and RME theory specifies the trajectory of that sequence more fully than it specifies the perceptual media through which each level is realised. Multisensory instruction supplies exactly this. In the present study, multisensory treatment comprises four channels, each aligned with a distinct RME principle. Kinesthetic activity, whole-body enactment of context situations operationalises the activity principle, since bodily action constitutes the earliest form of mathematical doing. Tactile activity, manipulation of structured materials whose physical affordances embody mathematical constraints furnishes the initial "model-of" in emergent modelling. Visual activity, construction and annotation of schematic representations such as number lines and bar models provides the vertical instruments through which a model-of becomes a model-for. Auditory activity, verbal explanation, justification, and negotiation of notation enacts the interactivity principle by making informal strategies public and available for comparison. RME's intertwinement principle further motivates their combination rather than their separate deployment. In the present intervention, multisensory RME is conceptualised as a way of materially realising progressive mathematization in the primary classroom; this is a proposed instructional integration rather than a mechanism separately tested in the study (Jitendra et al., 2024; Ponte et al., 2023; Post & Prediger, 2024).

The Realistic Mathematics Education (RME) approach in Indonesia is increasingly being integrated with multisensory learning, which engages several senses to strengthen students' understanding of mathematical concepts (Anjarwati et al., 2025; Melhem et al., 2025; Siller &

Ahmad, 2024). Traditional RME emphasizes real-world contexts, while multisensory activities can further support students' engagement through varied learning experiences (Mayer, 2024; Rasyid et al., 2025). Recent research suggests that integrating multisensory activities into RME may support engagement and disposition under certain instructional conditions, although the effects cannot be assumed to extend to every mathematics outcome (Nugraha & Samsudin, 2024; Sari et al., 2025). This approach offers a potentially meaningful, holistic, and student-centred learning experience in response to continuing numeracy challenges in Indonesia.

Although many studies have examined RME in Indonesia (Fajri et al., 2025; Febrilia et al., 2025; Kurnaedi et al., 2024) and its contribution to conceptual understanding (Arhalifi et al., 2024; Netriwati et al., 2025; Ramadhan et al., 2025) and mathematical communication (Siswantari et al., 2025; Ng et al., 2025), studies examining the integration of multisensory RME for both conceptual understanding and mathematical disposition among elementary school students remain limited. Existing studies often focus on one domain or examine separate digital learning media, such as e-modules (Fadhilaturrahmi & Ananda, 2025; Muhammad et al., 2025). Teachers' readiness to implement contextual RME also requires further investigation (Al Maqbali, 2025; Do et al., 2021). The present study seeks to address this gap within the context of Indonesia's current curriculum, which encourages holistic, inclusive, and contextual learning. It is also relevant to Sustainable Development Goal 4 on quality education and the national *Asta Cita* priority of strengthening human resource development from an early age. Reviews of RME research identify continued interest in learning trajectories, instructional representations, and technology-supported contexts, but these strands do not by themselves establish the effectiveness of a combined multisensory intervention on two outcomes (Bayrak & Aslanci, 2022; Fajri et al., 2025).

Based on these considerations, this study aimed to describe the implementation of multisensory-enriched RME in mathematics learning and to examine differences in students' conceptual understanding and mathematical disposition between the experimental and control classes. The findings are expected to provide empirical evidence to inform meaningful mathematics instruction and support elementary school numeracy.

METHODS

This study employed an exploratory sequential mixed-methods design. Data were collected and analysed in two successive phases. The first, qualitative phase explored students' difficulties in learning mathematics and the implementation of multisensory-enriched Realistic Mathematics Education (RME) in an elementary school. The second, quantitative phase used a quasi-experimental pretest–posttest control-group design. A quasi-experimental approach was selected to examine the learning intervention in existing classes without reorganizing the established class structure (Nugraha & Samsudin, 2024; Netriwati et al., 2025).

The study population comprised sixth-grade students in an elementary school implementing the Independent Curriculum. Cluster sampling was used to select the experimental and control classes (Mutaqin et al., 2021; Soesanto & Dirgantoro, 2025). A total of 70 students participated, with 35 students in each class. The experimental class received mathematics instruction using multisensory-enriched RME, incorporating visual, auditory, kinesthetic, and tactile activities. The control class received conventional, teacher-centred mathematics instruction.

Data collection instruments were designed to gather both qualitative and quantitative data. Qualitative data were obtained using classroom observation sheets and interview guidelines. Quantitative data were collected using instruments reported as having undergone validity and reliability testing: (1) an essay-based test of students' mathematical conceptual understanding, administered as a pretest and posttest; and (2) a Likert-scale questionnaire measuring mathematical disposition. Combining cognitive (conceptual understanding) and affective (mathematical disposition) measures was intended to provide a more comprehensive picture of students' mathematical learning (Febriyani et al., 2022; Nugraha & Samsudin, 2024; Soesanto &

Dirgantoro, 2025).

Qualitative data were analysed descriptively through data reduction, data display, and conclusion drawing. Quantitative data were analysed using SPSS through preliminary assumption checks and hypothesis testing. The preliminary analyses included a normality test and an independent-samples t-test to compare the groups' pretest scores. The main hypothesis was examined using Multivariate Analysis of Variance (MANOVA), with Wilks' Lambda as the multivariate test statistic. The multivariate test was intended to assess group differences across the combined cognitive and affective outcomes while limiting the risk of multiple-testing errors (Nugraha & Samsudin, 2024; Siller & Ahmad, 2024). Figure 1 presents the mixed-methods research flowchart.

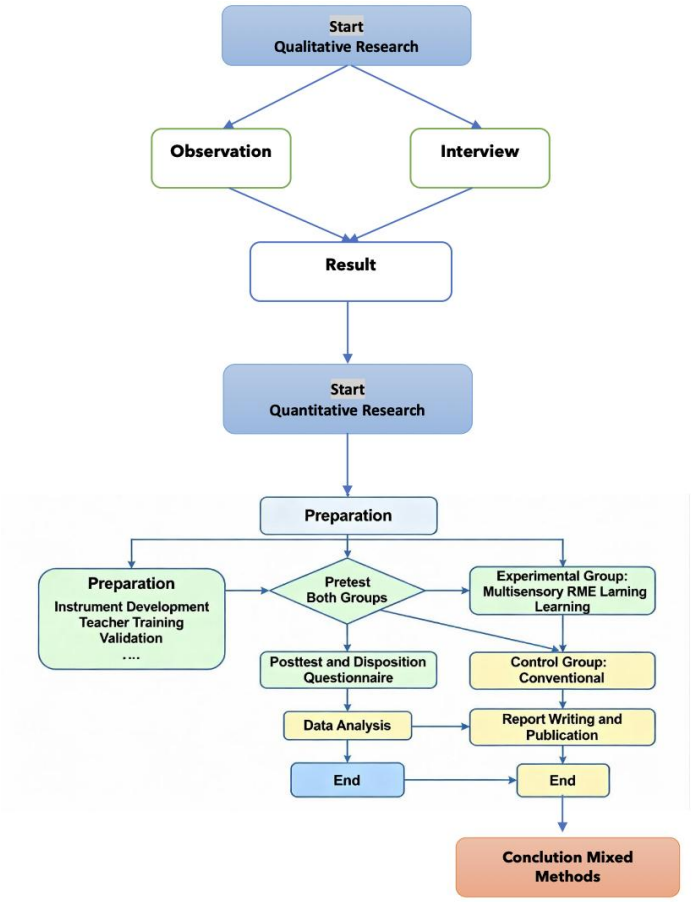


Figure 1. Mixed Methods Research Flowchart

RESULTS AND DISCUSSION

Qualitative Research Findings

This section presents qualitative findings from two sources: (1) learning-attitude observation sheets completed by the teacher for 35 sixth-grade students at Jatimulya 11 State Elementary School, Bekasi Regency, during four lessons on cubes and cuboids using multisensory-enriched RME; and (2) semi-structured interviews with 33 students after the lessons. The data were analysed through reduction, thematic categorisation based on the interview indicators (initial experiences, conceptual understanding, multisensory learning, learning difficulties and strategies, engagement and mathematical disposition, and reflections and suggestions), and comparison with observation scores. Five themes emerged, as presented in Table 1 and discussed below in relation to the research questions.

Table 1. Themes and Categories of Qualitative Data Analysis Results

Code	Theme	Categories and initial codes	Representative evidence	Analytic interpretation	Data source
T1	Implementation of multisensory RME	Realistic contexts: everyday objects used as starting points (cardboard, shoe boxes, Rubik's cube) Tactile–visual activities: touching and feeling solids; measuring; constructing frames from chopsticks and plasticine	"I brought a Rubik's Cube, Miss, because it's box-shaped." ([S-3], interview) "Yes, Miss, it's shaped like a cube; this is a 3x3 Rubik's Cube, Miss." ([S-3], interview) Field notes: [Student brought an object matching a geometric shape, Meeting 1]	Learning started from objects students already knew and moved toward the formal concepts of cube and cuboid. Handling and building the solids gave students a physical reference for edges, faces and vertices, which supports the RME principle of progressive mathematisation from a real context.	Interviews (33 students); classroom observation
T2	Conceptual understanding	Identifying properties: students name and distinguish the faces, edges and vertices of cubes and cuboids Persistent difficulties: accuracy in drawing nets; applying the volume formula	"Yes, I find it easier to remember the concept because I can see and touch the object." ([S-1], interview) "If I can feel and touch it—and also see it directly..." ([S-8], interview)	Understanding was stronger for properties that could be seen and touched directly than for tasks requiring a shift to two-dimensional representation (nets) or symbolic procedure (volume formula). This marks the point where concrete experience had not yet been fully connected to formal mathematics.	Interviews (33 students)
T3	Strategies for coping with	Seeking help: asking the	"It was really hard when I was	Students responded to	Interviews (33

Code	Theme	Categories and initial codes	Representative evidence	Analytic interpretation	Data source
	difficulty	teacher or a friend Self-regulation: repeating the activity; rethinking before answering	building that block structure; the pieces wouldn't stick and kept falling... but I managed to fix it in the end." ([S-4], interview) "The most exciting experience was assembling the chopsticks into a block structure." ([S-4], interview)	difficulty with both social strategies and individual checking rather than giving up. This indicates that the learning environment made help-seeking acceptable and encouraged students to monitor their own answers.	students)
T4	Mathematical disposition	Self-confidence: increased confidence in doing mathematics Preference for concrete learning Interest: willingness to repeat the activities	"After trying it out, I was able to assemble the cubes and rectangular prisms, Miss." ([S-4], interview) "I tried it a few times first, Miss, and only then did I understand how to make the cubes and rectangular prisms." ([S-8], interview) Field notes: Students attempted to assemble the prepared materials to construct cubes and rectangular prisms.	Students linked their confidence and interest to the hands-on nature of the tasks. The wish to repeat the activities suggests that the multisensory approach affected attitudes toward mathematics and not only task performance.	Interviews (33 students); classroom observation
T5	Affective–social attitudes (contextual numeracy)	Teamwork: cooperation within groups Accuracy: care in measuring and constructing Responsibility: completing the assigned task	Field notes: They work with their respective group members; if they encounter difficulties, they consult the teacher immediately.	Group construction tasks required students to share materials, check measurements together and finish a common product. These behaviours show numeracy being exercised in a social, contextual setting.	Classroom observation (35 students)

Use of Multisensory-Enriched RME in Elementary Mathematics Learning

To address the first research question, interview and observation data indicated that multisensory-enriched RME was implemented through three interconnected activities: the

presentation of realistic contexts, multisensory exploration (visual, tactile, and kinesthetic), and collaborative model construction. These stages are consistent with contextual geometry instruction in which tangible models serve as a starting point for subsequent abstraction (Mutaqin et al., 2021; Ponte et al., 2023).

Presenting Realistic Contexts as the Starting Point for Learning

The teacher introduced familiar everyday objects, such as shoe boxes, packaging boxes, dice, and Rubik's cubes, as a bridge to the abstract concepts of cubes and cuboids. Many interviewed students spontaneously recalled particular concrete objects when asked about their learning experiences, suggesting that the realistic contexts remained memorable to them. Connecting familiar objects with disciplinary vocabulary is also recommended in representationally rich mathematics instruction (Cordero-Siy & Ghousseini, 2022; Jitendra et al., 2024).

> *"The Rubik's cube. In the Rubik's cube problem, it looks like it's made up of a lot of little unit boxes, so we can just count them." (S3, on what helped most in understanding cubes)*
> *"Dice. Dice are shaped like cube. So you know form cube That like dice." (S5)*

This strategy is consistent with guided reinvention in RME, whereby students reconstruct mathematical concepts through meaningful real-life experiences rather than receiving formal definitions at the outset. This interpretation is compatible with recent RME studies on contextual tasks and elementary geometry (Do et al., 2021; Mutaqin et al., 2021; Utami et al., 2025).

Multisensory Exploration: Touching, Measuring, and Assembling

Core learning activities involved multiple sensory channels: students examined the shapes of objects by touch, measured their sides, and assembled models of cubes and cuboids using wooden chopsticks and plasticine. Many students described assembling the models as their most memorable learning experience. Research on manipulatives suggests that learning depends on how the teacher connects object manipulation to underlying mathematical ideas (Ponte et al., 2023; Siller & Ahmad, 2024).

> *"Yes, it is me So feel more easy remember the concept Because I see and touch the object." (S1)*
> *"Yes, because Can seen directly, thought, felt, so that more easy For written." (S8)*
> *"The activity is Miss... who made it cubes (and) blocks ... using chopsticks and ... plasticine." (S5)*

These responses suggest that visual and tactile activities did more than add variety; they also provided concrete references for geometric properties, such as side length and face shape, before students represented these properties symbolically. Similar concerns about linking concrete, visual, and symbolic representations are discussed by Prain et al. (2023) and Post and Prediger (2024).

Collaborative Model Construction

Several students highlighted the social dimension of multisensory activities, particularly teamwork when assembling solid-geometry models. Some models initially collapsed or failed to hold together before the groups successfully completed them.

> *"The most exciting experience is moment stringing chopsticks together cube through Work The same group ... until successful." (S7)*
> *"My time for beam That difficult very until No stick and fall keep going ... but Finally Can corrected." (S4)*

This finding was supported by observation data: cooperation received the highest mean score among the five observed attitude indicators. The results suggest that the multisensory activities encouraged student interaction and collaboration alongside individual manipulation of concrete objects. Research also associates structured collaborative learning with engagement and mathematics achievement, while its size and consistency vary across settings (Sun et al.,

2022; Talkhan et al., 2025; Putri et al., 2025).

Students' Conceptual Understanding and Mathematical Disposition in Supporting Numeracy

The second research question was addressed through three related themes: understanding geometric concepts, students' learning difficulties and strategies, and mathematical disposition. Together, these themes illustrate aspects of students' developing numeracy skills.

Conceptual Understanding: Recognising Attributes but Struggling with Precision

Most students could describe cubes and cuboids in their own words, emphasising similarities and differences in side lengths as distinguishing features. This suggests conceptual understanding at a descriptive–attributive level (Van Hiele levels 1–2). However, recognizing attributes should not be equated with full mastery of geometric representation and reasoning (Ponte et al., 2023; Melhem et al., 2025).

> *"The cube is get up space that has equal sides. A rectangular prism is get up space that has long sides different." (S1)*
> *"If the cube all his side the same, the shape is like a box or square. If the block his side There are some differences ..." (S3)*

However, when students needed to express their understanding through mathematical representations, such as drawing nets or calculating volume and surface area, many reported difficulties with measurement precision and remembering formulas, despite being able to describe the geometric shapes. The difficulty of connecting geometric objects with nets and formulas is consistent with studies emphasizing explicit transitions among representational forms (Cordero-Siy & Ghousseini, 2022; Jitendra et al., 2024; Post & Prediger, 2024).

> *"I can But rather not enough understand that's it, because rather difficult. Usually the line rather past like that, no same." (S3)*
> *"According to I am the most difficult remember the formula." (S1)*
> *"Miss's volume ... I'm afraid the formula is wrong ... remembering The formula is also difficult." (S5)*

This gap between relatively strong descriptive understanding and developing procedural precision is important for numeracy, which requires not only understanding quantities and shapes but also measuring, calculating, and representing results accurately. Such a distinction is also highlighted in research differentiating procedural performance from conceptual reasoning (Stovner & Klette, 2022; Prain et al., 2023).

Strategies for Overcoming Difficulties: Asking, Repeating, and Using Concrete Objects

When they encountered difficult problems, students commonly reported asking teachers or friends for help and taking time to reconsider their answers rather than immediately giving up. Supportive peer interactions and teacher mediation are common features of active-learning environments (Sun et al., 2022; Woods & Copur-Gencturk, 2024).

> *"I think come back ma'am." (S1)*
> *"If it is difficult, it will ask and request teacher assistance." (S8)*
> *"Ask Miss or No ask to friend." (S5)*

The interviewed students generally reported that concrete objects and hands-on activities helped them overcome difficulties. They referred to familiar examples, such as shoe boxes and dice, which gave meaning to previously abstract questions. These active strategies—asking questions, reconsidering answers, and referring to concrete representations—may support independence and persistence in mathematics learning. The usefulness of tangible materials should nonetheless be judged by the conceptual relations students construct, not by physical handling alone (Ponte et al., 2023; Leukel et al., 2024).

Mathematical Disposition: Confidence, Preference, and Willingness to Repeat

Students' mathematical disposition was reflected in three recurring indicators across the interviews: increased self-confidence, a preference for concrete activities over reading textbooks alone, and enthusiasm for repeating hands-on learning experiences. Prior studies link RME-based learning environments and mathematics-related media with productive disposition and learner agency (Chua, 2021; Nugraha & Samsudin, 2024; Muhammad et al., 2025).

> *"Sense of trust self Because Already taught and given know how to ... I really want to, to repeat back to memory about the material the more strong." (S7)*
> *"More Like use the original object Because more Can understood. If from book just I not enough understand." (S1)*
> *"Of course I want to, because That more exciting Just like that, more attractive."*

Some students, including S1, still expressed uncertainty about their understanding, suggesting that positive mathematical disposition did not develop uniformly. Observation data showed that, among the 35 observed students, 18 (51.4%) achieved a high attitude score (18–20), 16 (45.7%) were in the moderate category (14–17), and one (2.9%) was in the low category (Table 2). These observations suggest that most students demonstrated positive learning attitudes during the four lessons. Differences in learners' experiences are also a reason to interpret affective gains contextually rather than assuming a uniform treatment response (Ampadu & Anokye-Poku, 2022; Soesanto & Dirgantoro, 2025).

Table 2. Distribution of Students' Learning Attitude Observation Scores (n = 35)

Category	Score Range (% of maximum)	Cutoff Criterion	Number of Students, n (%)	Interpretation
High	18–20 (90–100%)	At or near the maximum: total ≤ 2 points below 20, i.e., the attitude was shown consistently on virtually every indicator	18 (51.4%)	Consistently active, careful, self-confident, and collaborative throughout the multisensory activities
Moderate	14–17 (70–85%)	At or above the 70% minimum mastery threshold but below the near-maximum band	16 (45.7%)	Shows a positive attitude on most indicators, but not yet consistently on certain aspects (e.g., accuracy or participation)
Low	≤ 13 (≤ 65%)	Below the 70% minimum mastery threshold	1 (2.9%)	Requires intensive guidance on almost all affective indicators
Total			35 (100%)	

The Relationship Between Conceptual Understanding, Mathematical Disposition, and Numeracy

The qualitative findings suggest that conceptual understanding and mathematical disposition can complement each other in supporting numeracy. Concrete experiences helped students connect mathematical symbols, such as volume and surface-area formulas, with real objects and situations, moving learning beyond procedural memorisation. Positive disposition, reflected in self-confidence, persistence when model construction failed, and willingness to seek help, may

encourage engagement with tasks requiring accurate measurement and calculation. Observation notes also recorded students responding actively to contextual problems and persisting in finding solutions, behaviours relevant to classroom numeracy. Related work identifies associations between disposition, conceptual understanding, and classroom learning opportunities without treating these constructs as interchangeable (Febriyani et al., 2022; Soesanto & Dirgantoro, 2025; Supriadi et al., 2024).

Student Reflections and Suggestions

In their reflections, most students reported that multisensory-enriched RME made the material easier to understand, and many did not suggest specific improvements. Some students nevertheless offered constructive suggestions for future learning activities.

> *"Suggestion to in front of it looks like... doing activities (activities) his activities more Lots again)." (S5)*
>
> *"I hope every Study get up room There is example the object so that I understand better." (S1)*
>
> *"I want to more methods explain and practice directly", with portion memorization reduced formula.*

Taken together, these suggestions support providing more opportunities for hands-on activities rather than relying mainly on formula memorisation. This recommendation is consistent with the RME principle that mathematics should be constructed through meaningful human activity, not only learned as a finished product. Recent RME and manipulative-based studies similarly stress the need to connect practical activities with increasingly formal mathematical representations (Fauzan et al., 2024; Siller & Ahmad, 2024; Netriwati et al., 2025).

Summary of Qualitative Findings

Overall, the qualitative findings show that multisensory-enriched RME was implemented through realistic contexts, visual–tactile–kinesthetic exploration, and collaborative model construction. These activities were positively received by students, and most obtained high or moderate learning-attitude observation scores. Students demonstrated relatively strong understanding of the descriptive attributes of cubes and cuboids but continued to face difficulties with procedural precision, particularly nets and volume formulas. Their mathematical disposition was reflected in self-confidence, a preference for concrete learning, and persistence when facing difficulties. Together, these findings provide qualitative context for the quantitative results presented in the following section.

Quantitative Research Findings

Descriptive Analysis of Research Data

This study involved two groups: an experimental class taught using multisensory-enriched Realistic Mathematics Education (RME) and a control class taught using conventional instruction. Cognitive outcomes were measured through pretest and posttest conceptual-understanding scores, while the affective outcome was measured using mathematical-disposition scores. Descriptive statistics for both groups are presented in Table 3.

Table 3. Descriptive Statistics of Student Performance

Group	Variable	*n*	Mean	*SD*	95% CI for the Mean
Experimental class	Conceptual understanding (pretest)	35	56.57	10.41	[52.99, 60.15]
	Conceptual understanding (posttest)	35	90.69	5.85	[88.68, 92.70]
	Mathematical disposition	35	119.05	9.41	[115.82, 122.28]
Control class	Conceptual understanding (pretest)	35	53.43	9.53	[50.16, 56.70]
	Conceptual understanding (posttest)	35	68.46	7.47	[65.89, 71.03]
	Mathematical disposition	35	102.05	10.79	[98.34, 105.76]

Note. n = number of students; SD = standard deviation; CI = confidence interval; LL = lower limit; UL = upper limit. The 95% CI is computed as Mean ± $t(0.975, n-1) \times SD/\sqrt{n}$.

Table 3 shows that the two classes started from similar levels of conceptual understanding (pretest means of 56.57 and 53.43). After the intervention, the experimental class had a higher posttest mean (90.69) than the control class (68.46). It also had a smaller spread of scores (SD = 5.85 vs. 7.47). The experimental class also scored higher on mathematical disposition (119.05 vs. 102.05). Descriptive statistics alone cannot show whether these differences are meaningful, so Tables 4–7 report gain scores, assumption checks, and inferential tests with effect sizes.

Table 4. Gain Scores and Normalized Gain (N-gain) in Conceptual Understanding

Group	Pretest Mean	Posttest Mean	Gain (Post−Pre)	N-gain <*g*>	Category
Experimental class	56.57	90.69	34.12	0.79	High
Control class	53.43	68.46	15.03	0.32	Medium

Note. N-gain <g> = (Posttest − Pretest) / (Maximum score − Pretest), with a maximum score of 100. Categories: g ≥ 0.70 = high; 0.30 ≤ g < 0.70 = medium; g < 0.30 = low.

The experimental class gained 34.12 points, more than twice the control class gain of 15.03. Its normalized gain (<g> = 0.79) is in the high category, while the control class (<g> = 0.32) is in the medium category. Students taught with the intervention therefore closed a much larger share of the possible improvement.

Pretest Group Comparison

Table 5. Independent Samples t-Test Results for Pretest Scores

Variables	t value	df	Sig. (2-tailed)	Conclusion
Pretest (Experimental vs. Control)	1.318	68	0.192	Not statistically significant

The independent-samples t-test results presented in Table 5 indicated no statistically significant difference in pretest scores between the experimental and control groups, t(68) = 1.318, p = .192. This finding suggests that the groups had comparable initial levels of conceptual understanding. However, the absence of a statistically significant difference does not necessarily establish equivalence between the two groups.

Hypothesis Testing and Multivariate Analysis

Table 6. Independent Samples t-Test Results for Post-test Scores

Variables	t value	df	Sig. (2-tailed)	Hypothesis Decision
Post-test (Experiment vs Control)	13.857	68	< .001	Rejected (Significant)

As shown in Table 6, the experimental and control classes differed significantly in posttest conceptual-understanding scores, t(68) = 13.857, p < .001. The null hypothesis of equal group means was therefore rejected, indicating higher posttest performance in the class taught using multisensory-enriched RME than in the conventionally taught class.

Table 7. Multivariate Test Results

Effect / Source	Multivariate Tests	Value	F Count	df Hypothesis	df Error	(Sig.)
Group/ Class	Wilks' Lambda	0.249	100.802	2	67	< .001

Based on the output in Table 7, the Wilks' Lambda test produced a value of Λ = 0.249, F(2, 67) = 100.802, p < 0.001. Because the reported significance level (p < .001) is below 0.05, H0 is rejected. The corresponding multivariate effect size was partial η2 = 0.751, indicating a substantial multivariate difference. This multivariate result indicates a significant difference between groups on the combined measured outcomes. Prior to the MANOVA, the assumption of

homogeneity of covariance matrices was examined using Box's M test (Box's M = 2.859, p = 0.428), and the homogeneity of variances for each dependent variable was examined using Levene's test (p = 0.36 and 0.90).

Discussion

The findings indicated higher posttest conceptual-understanding scores in the experimental class than in the control class. Although the pretest difference was not statistically significant (p = .192), the experimental class attained a mean posttest score of 90.69 compared with 68.46 in the control class. The MANOVA result (Wilks' Lambda, p < .001) also indicated a statistically significant multivariate group difference. These findings are consistent with a beneficial association between multisensory-enriched RME and the measured learning outcomes, although the non-randomised design limits causal interpretation.

These findings align with the study's aim of examining the integration of multisensory activities within Realistic Mathematics Education (RME) to support elementary students' conceptual understanding. The higher scores in the experimental class may be related to RME's emphasis on familiar real-world contexts when introducing abstract mathematical concepts (Anjarwati et al., 2025; Fauzan et al., 2024; Netriwati et al., 2025; Utami et al., 2025). Through progressive mathematization, students are encouraged to reconstruct mathematical principles rather than merely memorise formulas, reflecting the principle of guided reinvention. Such meaningful reasoning may help students develop stronger conceptual connections. Related applications of RME and classroom media report positive outcomes in primary mathematics, but differ in content, samples, and designs (Nugraha & Samsudin, 2024; Ramadhan et al., 2025; Pramuditya et al., 2025).

The effect of the RME approach appears to be strengthened when realistic problem solving is combined with multisensory activity, in which students see visual demonstrations, listen to explanations, and handle concrete materials. This is consistent with the developmental characteristics of elementary school students, for whom structured concrete experiences can serve as a bridge to formal mathematical representations (Ponte et al., 2023; Melhem et al., 2025). Because this study did not collect neurological data, the result is interpreted pedagogically rather than neurologically. From a cognitive load perspective, presenting information through complementary visual and verbal channels and anchoring it in a familiar context may reduce extraneous load and free working memory for the mathematical structure of the problem (Castro-Alonso et al., 2021; Mayer, 2024). From a representational perspective, the activities let students move from enactive to iconic to symbolic representations (Jitendra et al., 2024), which parallels the progression from "model of" to "model for" in RME (Mutaqin et al., 2021; Fauzan et al., 2024), and coordinating several representations of the same concept is central to mathematical understanding (Cordero-Siy & Ghousseini, 2022; Post & Prediger, 2024). From an embodied learning perspective, manipulating objects and using gesture ground abstract ideas in physical action (Seccia & Goldin-Meadow, 2024), and instruction with concrete manipulatives has been found to benefit learning and retention (Ponte et al., 2023; Siller & Ahmad, 2024). Together, these perspectives offer a plausible explanation for the stronger conceptual understanding observed, although the mechanisms themselves were not directly measured in this study. It is important not to attribute this difference to sensory integration alone: Leukel et al. (2024) found no improvement in primary pupils' accuracy or response speed when visual and somatosensory information were combined in a different geometry task. More generally, evidence on instructional representations suggests that guided connections among modalities, rather than their mere presence, are critical (Castro-Alonso et al., 2021; Prain et al., 2023).

The second outcome examined in this study was mathematical disposition. The experimental class obtained a higher mean disposition score (M = 119.05, SD = 9.41) than the control class (M = 102.05, SD = 10.79). Although the experimental class had a slightly smaller standard deviation, these descriptive results alone do not establish that students' attitudes became more uniform after the intervention.

Multisensory-enriched RME provides opportunities for students to explore mathematical

problems through varied activities, which may strengthen their engagement and confidence (Chua, 2021; Nugraha & Samsudin, 2024; Putri et al., 2025). Successful experiences in solving problems may support self-confidence, perseverance, curiosity, and a positive appreciation of mathematics (Ampadu & Anokye-Poku, 2022; Soesanto & Dirgantoro, 2025). Such dispositions may contribute to numeracy learning under the Independent Curriculum (Fadhilaturrahmi & Ananda, 2025; Muhammad et al., 2025). However, mathematics anxiety was not measured directly in this study. The results therefore suggest that multisensory-enriched RME may support both conceptual understanding and mathematical disposition, rather than demonstrating effects on unmeasured affective outcomes. Evidence from instructional technology and image-based media further indicates that engagement is sensitive to media design, interactivity, and the role of the teacher; such findings should be treated as complementary pedagogical context rather than direct tests of ME-RME (Rasyid et al., 2025; Sari et al., 2025; Al Maqbali, 2025).

CONCLUSION

This study examined the implementation of Multisensory-Enriched Realistic Mathematics Education (ME-RME) in sixth-grade mathematics learning and its relationship with students' conceptual understanding and mathematical disposition. The qualitative findings indicated that ME-RME was implemented through three main activities: presenting realistic contexts, multisensory exploration (visual, tactile, and kinesthetic), and collaborative model construction. Students generally responded positively to these activities and demonstrated an understanding of geometric properties, although some continued to experience difficulties with drawing nets, measurement precision, and applying mathematical formulas. Their mathematical disposition was reflected in self-confidence, a preference for concrete learning activities, and persistence in overcoming difficulties.

The quantitative findings showed that the experimental group achieved higher posttest scores than the control group in conceptual understanding ($M = 90.69$ vs. 68.46) and mathematical disposition ($M = 119.05$ vs. 102.05). The multivariate analysis also indicated a statistically significant difference between the groups (Wilks' $\Lambda = .249$, $F(2, 67) = 100.80$, $p < .001$). These findings suggest that ME-RME may be a promising instructional approach for helping students connect abstract mathematical concepts with concrete experiences while supporting positive mathematical dispositions. Teachers may consider integrating realistic contexts and multisensory activities into elementary mathematics instruction.

However, this study was limited to two intact classes in one elementary school, with a relatively short intervention and non-random group allocation. Therefore, the findings should be interpreted cautiously and cannot be widely generalized. Furthermore, numeracy skills and mathematics anxiety were not directly measured. Future research involving larger and more diverse samples, longer interventions, and additional measures of mathematical disposition and numeracy is recommended to validate and extend these findings. Future studies could also examine which components of the combined intervention contextual problems, manipulative activities, representational transitions, or collaboration contribute most strongly to each outcome, as recent reviews have identified important variation among mathematics teaching designs.

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