

Realistic Mathematics Education for 21st Century Skills: Strengthening Collaboration and Critical Thinking in Mathematics Learning


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ABSTRACT

The development of 21st-century skills, particularly collaboration and critical thinking, has become a central objective in contemporary mathematics education. The Realistic Mathematics Education (RME) approach is considered a promising intellectual strategy for supporting these competencies through contextual problem-solving activities and structured social interactions. However, empirical evidence on the simultaneous contribution on both critical thinking and collaborative skills remains limited. This study aims to assess the effect of the RME approach on students' critical thinking and collaborative skill in mathematics learning. A quantitative approach using a quasi-experimental pretest–posttest control group design involving sixty students, divided into an experimental group receiving RME instruction ($n = 30$) and a control group receiving conventional instruction ($n = 30$). The research instruments included a critical thinking skills test and an observation-based collaboration skills assessment. Data were analyzed using Multivariate analysis of Covariance to assess the combined effects of RME while controlling for initial abilities. The results revealed that the experimental group showed significantly higher posttest scores in critical thinking skills ($M = 82.15$) compared to the control group ($M = 70.46$), with N-Gain scores of 0.61 and 0.35, respectively. Similarly, students' collaborative skills in the experimental group ($M = 84.27$) were higher than those in the control group ($M = 71.15$). Multivariate analysis confirmed a statistically significant effect of RME on both critical thinking and collaboration. These findings suggest that RME effectively enhances students' cognitive and social competencies and can serve as an alternative strategy for mathematics instruction.

Keywords: Collaborative Skill, Critical Thinking, Mathematics Learning, Realistic Mathematics Education.

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Introduction

The development of mathematics learning in the 21st century emphasizes not only the mastery of mathematical concepts but also strengthening students' higher-order thinking and social interaction skills, particularly critical thinking and collaborative skills. In mathematics education, these competencies are essential because students are expected to analyze problems logically, evaluate solution strategies and work collaboratively to construct meaningful mathematical understanding in various learning situations (Kwangmuang et al., 2021).

Critical thinking skills are essential in supporting students' ability to understand mathematical problems deeply, identify relevant information, evaluate alternative strategies, and draw logical conclusions. In mathematics learning, critical thinking is reflected through activities such as interpreting contextual problems, selecting appropriate solution producers, and verifying the correctness of obtained results (Alkhatib, 2019; Adhikari et al., 2025). Students who possess strong critical thinking skills tend to approach mathematical problems more systematically and reflectively (Sachdeva & Eggen, 2021).

In addition to critical thinking, collaboration skills are also essential in mathematics learning. Collaboration refers to students' ability to interact constructively with peers to exchange ideas, negotiate meaning, and develop shared understanding during problem-solving activities (Tohani & Aulia, 2022). Through collaborative learning processes, students are encouraged to communicate mathematical reasoning, compare solution strategies, and refine their understanding through meaningful social interaction.

However, several studies indicate that students' critical thinking and collaboration skills in mathematics learning remain relatively low. International assessment results such as the Programme for International Student Assessment demonstrate that many students still experience difficulties in solving mathematical problems requiring higher-order reasoning and contextual interpretation (Xu et al., 2023). This condition suggests that mathematics instruction in many classrooms has not yet optimally supported the development of students' critical thinking and collaboration skills.

One contributing factor to this issue is the continued dominance of teacher-centered instructional practices. Conventional mathematics teaching often emphasizes procedural exercises and direct explanation of formulas, which limits students' opportunities to actively explore ideas, discuss alternative strategies, and engage in collaborative problem solving (Erdogan, 2019). Therefore, a learning approach that supports contextual learning experiences and promotes active student interaction is needed.

Realistic Mathematics Education is considered an appropriate approach to address these challenges. Developed by Freudenthal, this approach views mathematics as a human activity learned through meaningful engagement with contextual problems connected to students' real-life experiences (Van den Heuvel-Panhuizen, 2019). Through contextual problem-solving activities, students are encouraged to actively construct mathematical knowledge through exploration, discussion, and reflection.

Furthermore, Realistic Mathematics Education emphasizes key principles such as the use of real-world contexts as learning starting points, progressive mathematization processes, and social interaction during learning activities (Van den Heuvel-Panhuizen & Drijvers, 2020). These principles provide opportunities for students to develop multiple solution strategies collaboratively while simultaneously strengthening their reasoning and critical thinking processes.

Previous studies show that implementing Realistic Mathematics Education can improve students' conceptual understanding, problem-solving skills, and engagement in mathematics learning (Sumirattana et al., 2017; Anggraini & Fauzan, 2020). However, empirical investigations that explicitly analyze its simultaneous impact on students' critical thinking and collaborative skills using a multivariate analytical framework remain limited, particularly in secondary mathematics learning contexts. Most existing studies primarily emphasize cognitive learning outcomes rather than examining how Realistic Mathematics Education supports the development of higher-order thinking and collaborative competencies in the same instructional environment (Ventistas et al., 2025; Nugraheni & Marsigit, 2021).

Furthermore, existing studies examining collaboration and critical thinking skills in mathematics learning are often conducted separately or in different instructional contexts. As a result, there remains limited empirical evidence explaining how a contextual learning approach such as Realistic Mathematics Education supports the integration of cognitive reasoning processes and collaborative interactions within a single instructional design. This limitation indicates the need for research that investigates how the principles of contextual problem solving, progressive mathematization, and social interaction embedded in Realistic Mathematics Education support the development of both collaboration and critical thinking skills simultaneously.

Because critical thinking skills and collaborative skills are conceptually interconnected and frequently develop simultaneously in contextual, and interaction-based mathematics learning environments, examining these competencies within a multivariate analytical framework is important. Investigating both variables together allows a more comprehensive understanding of how instructional approaches such as Realistic Mathematics Education support the integration of cognitive reasoning processes and collaborative engagement in mathematics classrooms.

Therefore, the contribution of this study lies not merely in examining two variables together, but in empirically investigating how the instructional characteristics of Realistic Mathematics Education create learning situations that support students'

collaborative engagement and critical reasoning processes during mathematics learning activities. By analyzing these two competencies within a unified instructional framework, this study provides additional empirical evidence regarding the role of context-based mathematics learning in facilitating the development of students' higher-order thinking and collaborative skills. Based on the identified research gap, this study aims to investigate the effect of the Realistic Mathematics Education approach on students' critical thinking and collaborative skills simultaneously by controlling for students' initial abilities using a multivariate analytical framework.

Methods

This study employed a quantitative approach using a quasi-experimental pretest–posttest control group design to analyze the impact of implementing the Realistic Mathematics Education approach on students' collaboration and critical thinking skills in mathematics learning. A quasi-experimental design was selected because the study involved intact classroom groups that could not be randomly assigned individually, which is common in educational research settings (Creswell & Creswell, 2017; Fraenkel & Wallen, 1990). The design involved two groups of students: an experimental group receiving instruction based on the Realistic Mathematics Education approach and a control group receiving conventional mathematics instruction commonly used in classroom practice. Both groups completed a pretest prior to the intervention and a posttest after the intervention to measure changes in students' critical thinking skills, while collaboration skills were assessed through structured classroom observations conducted during the learning process.

Research Location and Participant

This study was conducted at MTs Negeri 1 Yogyakarta during the odd semester of the 2025/2026 academic year. The research site was selected using purposive sampling based on the school's willingness to participate and the compatibility of its mathematics curriculum with the research objectives (Cohen, 2013).

The research participants consisted of eighth-grade students selected using cluster random sampling. From the available intact classes, two classes were randomly selected to participate in the study. One class was assigned as the experimental group and the other as the control group, with 30 students in each group. Cluster random sampling is commonly used in classroom-based experimental studies where participants are naturally organized into instructional groups (Fraenkel & Wallen, 1990).

Research Procedure

The research procedure consisted of three stages: preparation, implementation, and data analysis.

Preparation Stage

During the preparation stage, the researchers developed learning instruments based on the principles of Realistic Mathematics Education, including lesson plans, contextual student worksheets, and supporting learning media designed to facilitate exploration and group discussion. Research instruments consisting of a critical thinking skills test and a collaboration skills observation sheet were also developed and validated by three experts in mathematics education to ensure content validity and alignment with research variables. Expert judgment is widely recommended to establish content validity in educational instrument development (Creswell & Creswell, 2017). A pilot study involving students with similar characteristics to the research participants was conducted to examine instrument reliability. Reliability testing using Cronbach's alpha indicated satisfactory internal consistency for both instruments, which is acceptable for classroom-based educational research (Field, 2024).

Implementation Stage

During the implementation stage, the experimental group received instruction using the Realistic Mathematics Education approach, which emphasized contextual problem-solving, progressive mathematization, and collaborative learning interactions. Students worked in small groups to explore contextual problems, construct mathematical representations, and present their solution strategies. Meanwhile, the control group received conventional instruction characterized by teacher explanations followed by individual practice exercises. Both groups completed a pretest before the intervention and a posttest after the intervention using equivalent instruments.

Data Collection Stage

Data were collected using two main techniques: critical thinking skills tests and classroom observations of students' collaborative skills. The critical thinking skills test was administered before and after the intervention to measure students' cognitive development during the learning process. In contrast, collaboration skills were assessed through structured observations conducted throughout the implementation of group learning activities. In addition, supporting documentation, such as students' worksheets and records of classroom learning activities, was collected to strengthen the interpretation of students' learning processes and interaction patterns during the

intervention. The use of multiple sources of classroom data is recommended to enhance the credibility of findings in educational research contexts (Cohen, 2013).

Research Instruments

Two research instruments used in this study, are critical thinking skills test and collaboration skills observation sheets. Both instruments were developed based on theoretical indicators of higher-order thinking skills and collaborative learning competencies commonly applied in mathematics education research. Before implementation, the instruments were reviewed and validated by two university lecturers specializing in mathematics education and educational assessment to ensure alignment between instrument indicators and the constructs of students' mathematical critical thinking and collaboration skills, as well as consistency with the principles of the Realistic Mathematics Education approach. Based on the experts' recommendations, several revisions were made to improve the clarity of problem statements, the suitability of rubric descriptors, and the consistency between assessment indicators and learning activities implemented during the intervention. This validation process strengthened the content validity of the instruments before they were administered to the research participants.

Critical Thinking Skills Test

Students' critical thinking skills were measured using open-ended mathematical problem-solving tasks developed based on four operational indicators: analyzing contextual mathematical problems, identifying relevant mathematical information, developing appropriate solution strategies, and evaluating the correctness of solutions. Each indicator was assessed using an analytic rubric-based scoring system ranging from 0 to 4 based on response accuracys, quality of reasoning, and completeness of solution steps.

Table 1. Critical Thinking Skill Scoring Rubric

Indicator	Score 4	Score 3	Score 2	Score 1	Score 0
Analyzing contextual problem	Accurate interpretation and clear understanding of relationships	Mostly correct interpretation	Partial understanding	Incorrect interpretation	No response
Identifying relevant information	Identifies all relevant information correctly	Identifies the most relevant information	Identifies some relevant information	Identifies incorrect information	No response
Developing solution strategies	Logical and efficient strategy	Appropriate but less efficient strategy	Partially appropriate strategy	Incorrect strategy	No response
Evaluating correctness of solutions	Complete evaluation with justification	Evaluation with limited justification	Incomplete evaluation	No evaluation	No response

The scoring rubric used in this study is presented in [Table 1](#). Open-ended mathematical tasks accompanied by analytic scoring rubrics allow students to demonstrate reasoning processes explicitly and are widely recommended for assessing higher-order thinking skills in mathematics learning contexts (Fraenkel & Wallen, 1990).

Collaboration Skills Observation Sheet

Students' collaboration skills were assessed using a structured observation rubric consisting of four indicators: active participation in group discussions, contribution of ideas during problem solving, responsiveness to peers' opinions, and responsibility in completing group tasks. Each indicator was rated using a four-point performance scale ranging from very low to very high participation levels. The collaboration assessment rubric is presented in [Table 2](#).

Table 2. Collaboration Skill Observation Rubric

Indicator	Score 4	Score 3	Score 2	Score 1	Score 0
Active participation	Consistently participates and encourages peers	Frequently participates	Occasionally participates	Rarely participates	Does not contribute ideas
Contribution of ideas	Provides relevant and constructive ideas regularly	Provides relevant ideas occasionally	Provides limited ideas	Provides limited ideas	Does not contribute ideas
Responsiveness to peers	Responds respectfully and builds on peers' ideas	Responds appropriately	Limited response	Limited response	Ignores peers' ideas
Responsibility for tasks	Completes tasks independently and supports group work	Completes assigned tasks responsibly	Completes tasks with reminders	Completes tasks with reminders	Does not complete tasks

Observations were conducted systematically during group learning activities throughout the intervention sessions to capture students' authentic interaction behaviors in collaborative learning settings. Observation-based assessment is commonly used to evaluate students' social interaction competencies in cooperative classroom environments because it allows researchers to document behavioral evidence directly during learning activities (Cohen, 2013). Reliability testing using Cronbach's alpha indicated acceptable internal consistency for the critical thinking skills test ($\alpha = 0.87$) and the collaboration skills observation sheet ($\alpha = 0.84$), which fall within the recommended reliability range for educational measurement instruments (Field, 2024).

Data Analysis Techniques

Data were analyzed using SPSS through several sequential stages.

First, assumption testing was performed to ensure that the data met the requirements for parametric multivariate analysis. Normality of data distribution was examined using the Kolmogorov–Smirnov test, while homogeneity of variance across groups was tested using Levene’s test (Field, 2024).

Second, Multivariate Analysis of Covariance (MANCOVA) was applied to examine the simultaneous effect of the Realistic Mathematics Education approach on students’ collaboration and critical thinking skills while controlling for differences in pretest scores between groups. MANCOVA is appropriate when multiple correlated dependent variables are analyzed together while adjusting for covariate effects in quasi-experimental educational research designs (Tabachnick & Fidell, 2019).

Third, follow-up univariate ANCOVA tests were conducted after the multivariate test indicated significant group differences to identify the specific contribution of the intervention to each dependent variable separately (Meyers et al., 2016). Finally, effect size analysis using partial eta squared was calculated to determine the magnitude of the intervention effect on students’ collaboration and critical thinking skills. Partial eta squared is widely used to interpret the strength of treatment effects in multivariate educational research and provides additional information beyond statistical significance testing (Field, 2024). All statistical analyses were conducted at a significance level of 0.05.

Result and Discussions

Descriptive statistics were calculated to examine students’ critical thinking skills and collaborative skills before and after the implementation of the Realistic Mathematics Education approach. The results showed that the average pretest scores of both groups were relatively comparable, indicating students in the similar initial abilities before the intervention. However, after the intervention, the posttest scores of students in the experimental group increased more substantially than those of in the control group (Table 3).

Table 3. Descriptive Statistics of Critical Thinking Skills

Group	Pretest Mean	Posttest Mean	N-Gain	Category
Experiment	54.32	82.15	0.61	Medium-High
Control	53.87	70.46	0.35	Medium

The interpretation of N-Gain scores in this study followed the classification proposed by Hake (1998) where an N-Gain score above 0.70 is categorized as high, between 0.30 and 0.70 as medium, and below 0.30 as low. Based on this classification, the improvement in students' critical thinking skills in the experimental group was categorized as medium to high, while the improvement in the control group was categorized as medium.

Table 4. Average Collaboration Skills Score

Group	Average	Category
Experiment	84.27	Very Good
Control	71.15	Good

Similarly, descriptive results also indicated differences in students' collaborative skills between groups (Table 4). Students in the experimental group demonstrated higher levels of participation in group discussions, greater contribution of ideas, stronger responsiveness to peers' perspectives, and higher responsibility in completing collaborative than those in the control group.

Assumption Testing for Multivariate Analysis

Before conducting hypothesis testing using Multivariate Analysis of Covariance, assumption tests were performed to ensure that the data met the requirements for parametric multivariate analysis. The results of Levene's test indicated that the assumption of homogeneity of variance was satisfied for both dependent variables; critical thinking skills ($F(1,58) = 0.807, p = .373$) and collaborative skills ($F(1,58) = 1.124, p = .293$). In addition, Box's M test confirmed the equality of covariance matrices between groups (Box's M = 6.284, $F = 1.012, p = .426$), indicating that the assumptions required for Multivariate Analysis of Covariance were satisfied (Table 5).

Because each group consisted of more than 30 students, the assumption of multivariate normality was considered acceptable based on the robustness of MANCOVA to moderate violations of normality. Therefore, the dataset met the statistical requirements for conducting Multivariate Analysis of Covariance to test the research hypotheses.

Table 5. Summary of Assumption Testing for MANCOA Analysis

Test	Variable	Sig.	Interpretation
Levene's Test	Critical Thinking	.373	Homogeneous
Levene's Test	Collaborative Skills	.293	Homogeneous
Box's M Test	Combined Variables	.426	Homogeneous covariance

Multivariate Analysis of Covariance was conducted to examine the simultaneous effect of the Realistic Mathematics Education approach on students' critical thinking and collaborative skills while controlling for pretest scores. The multivariate test based on Wilks' Lambda revealed a statistically significant effect of the learning approach on the combined dependent variables, Wilks' $\Lambda = 0.214$, $F(2,55) = 101.873$, $p < .001$, partial $\eta^2 = 0.786$. This result indicates that the Realistic Mathematics Education approach produced a strong multivariate effect on improving students' critical thinking and collaborative skills compared to conventional instruction.

To further identify the contribution of the intervention to each dependent variable, follow-up univariate ANCOVA tests were conducted after controlling for differences in pretest scores. The results showed that the learning approach had a statistically significant effect on students' critical thinking skills, $F(1,56) = 86.67$, $p < .001$, partial $\eta^2 = 0.607$. Similarly, a statistically significant effect was found for students' collaborative skills, $F(1,56) = 72.41$, $p < .001$, partial $\eta^2 = 0.564$. These findings indicate that students who participated in learning through the Realistic Mathematics Education approach achieved significantly higher adjusted posttest scores in both critical thinking and collaborative skills than those who experienced conventional learning.

Effect size analysis using partial eta squared demonstrated that the Realistic Mathematics Education approach contributed substantially to improvements in both learning outcomes. Based on commonly accepted interpretation criteria, the obtained effect sizes for critical thinking skills (partial $\eta^2 = 0.607$) and collaborative skills (partial $\eta^2 = 0.564$) fall within the large effect category, while the multivariate effect size (partial $\eta^2 = 0.786$) indicates a very strong combined effect of the intervention on both variables simultaneously. These results suggest that the implementation of the Realistic Mathematics Education approach provides meaningful educational contributions to enhancing students' higher-order thinking abilities and a collaborative engagement in mathematics learning.

The findings of this study demonstrate that implementing the Realistic Mathematics Education approach produced a statistically significant multivariate effect on students' critical thinking skills and collaborative skills after controlling for students' initial abilities. The results of the multivariate analysis based on Wilks' Lambda indicated that the instructional intervention significantly influenced the combined dependent variables simultaneously, confirming that the observed differences between the experimental and control groups were attributable to the learning approach rather than pre-existing differences in prior knowledge. This finding strengthens the argument that contextual mathematics instruction is important in supporting integrated cognitive and social learning outcomes in mathematics classrooms. The

large multivariate effect size obtained in this study further indicates that the Realistic Mathematics Education approach produced statistically significant improvements and generated meaningful pedagogical impacts on students' learning development. The magnitude of the effect sizes obtained in this study further strengthens the practical significance of the findings. The partial eta squared values for critical thinking skills ($\eta^2 = 0.607$) and collaborative skills ($\eta^2 = 0.564$) indicate large effects, while the multivariate effect size ($\eta^2 = 0.786$) reflects a very strong combined influence of the Realistic Mathematics Education approach on both learning outcomes simultaneously. These results suggest that the implementation of contextual mathematics instruction not only produces statistically significant improvements but also contributes substantially to meaningful changes in students' cognitive engagement and collaborative participation during mathematics learning. From an educational perspective, such large effect sizes indicate that the Realistic Mathematics Education approach represents a highly effective instructional strategy for supporting integrated higher-order thinking and social interaction competencies in classroom practice.

The improvement in students' critical thinking skills observed in the experimental group can be interpreted through the fundamental principles of the Realistic Mathematics Education approach, particularly the role of contextual problem exploration as the starting point of learning activities. Contextual mathematical situations provide opportunities for students to interpret real-world experiences mathematically and construct conceptual understanding through active engagement rather than passive reception of procedures. Recent studies confirm that contextualized mathematics instruction significantly enhances students' reasoning processes because it encourages learners to analyse situations, evaluate solution strategies, and justify mathematical conclusions during problem-solving activities (Sa'dijah et al., 2021; Toheri et al., 2020). These processes are central components of critical thinking development in contemporary mathematics education environments.

The descriptive findings of this study showed that students in the experimental group achieved higher posttest scores and higher normalized gain values compared to students in the control group, indicating stronger improvement in analysing contextual mathematical problems, identifying relevant mathematical information, developing solution strategies, and evaluating solution accuracy. These descriptive improvements are further confirmed by the ANCOVA results, which demonstrated that the observed differences remained statistically significant after controlling for students' initial abilities. These findings align with recent empirical research demonstrating that learning environments based on contextual mathematical modeling significantly improve students' higher-order thinking performance compared to conventional instruction (Thamrin et al., 2024; Saleh et al., 2018). Context-

based mathematical exploration allows students to construct knowledge through reflection and interpretation, strengthening conceptual understanding and supporting deeper reasoning abilities.

The effectiveness of the Realistic Mathematics Education approach in improving critical thinking skills is also closely related to the principle of progressive mathematization, which supports students' transition from informal reasoning to formal mathematical abstraction through guided learning trajectories. During the intervention sessions in this study, students were encouraged to collaboratively explore contextual problems and propose alternative solution strategies before receiving formal procedural explanations from the teacher. This structured learning trajectory supported students' reasoning flexibility and strengthened their ability to justify mathematical conclusions logically. Similar findings are reported in recent classroom intervention studies, indicating that progressive mathematization significantly contributes to students' reasoning development and problem-solving flexibility in mathematics learning environments (Palinussa et al., 2021; Sahara et al., 2024; Khairunnisak et al., 2024).

In addition to improving critical thinking skills, the findings of this study also demonstrated that the Realistic Mathematics Education approach significantly improved students' collaborative skills after controlling for initial differences between groups. The ANCOVA results confirmed that students in the experimental group achieved significantly higher collaboration scores than those in the control group, indicating that contextual group learning activities created opportunities for meaningful interaction among students during mathematical exploration. Students in the Realistic Mathematics Education class demonstrated stronger participation in group discussions, contributed more ideas during problem-solving processes, responded more actively to peers' opinions, and showed greater responsibility in completing shared tasks. These findings suggest that contextual learning environments support conceptual understanding and strengthen students' social interaction competencies during mathematics learning.

The improvement in students' collaborative skills can be explained through the structured interaction processes embedded within contextual group learning activities. Students in the experimental group were consistently engaged in collaborative mathematical problem-solving situations requiring them to exchange ideas, compare alternative strategies, and negotiate shared understanding through discussion. Recent studies on collaborative mathematics learning confirm that interaction-based learning environments significantly strengthen students' engagement and participation because they create opportunities for knowledge co-

construction and shared reasoning processes (Gillies, 2016; Kyndt et al., 2013). Collaborative mathematical discussions also encourage students to articulate reasoning explicitly, which supports both conceptual understanding and communication competence.

Furthermore, collaborative learning environments are widely recognized as essential components of contemporary mathematics instruction because they support the development of reasoning-based communication skills and collective knowledge construction. Research over the last decade indicates that student-centered mathematics instruction integrating contextual learning tasks and collaborative interaction structures significantly improves students' participation and learning motivation (OECD, 2019; Mercer et al., 2019). These interaction processes allow students to engage actively in mathematical discourse and develop confidence in expressing their reasoning during group problem-solving activities.

Importantly, the multivariate findings of this study indicate that the Realistic Mathematics Education approach simultaneously supported the development of both critical thinking and collaborative skills. The significant Wilks' Lambda result confirms that the intervention produced a combined effect on both dependent variables after controlling for pretest scores. This simultaneous improvement confirms that contextual mathematics instruction can support interconnected learning outcomes rather than isolated competency development, consistent with contemporary perspectives emphasizing integrated cognitive and social dimensions of mathematics learning. This finding highlights the potential of contextual mathematics instruction to foster integrated learning outcomes that reflect the competencies required for twenty-first-century education. Contemporary mathematics education frameworks emphasize that effective instructional practices should support procedural knowledge, reasoning ability, communication competence, and collaboration skills as essential components of mathematical literacy (OECD, 2021).

The integration of contextual learning and collaborative interaction structures within the Realistic Mathematics Education approach represents an instructional strategy aligned with the goals of twenty-first-century learning frameworks emphasizing critical thinking, collaboration, communication, and creativity. These competencies are increasingly recognized as essential outcomes of mathematics education because they prepare students to solve complex real-world problems requiring both analytical reasoning and cooperative interaction (Voogt & Roblin, 2017; Care et al., 2018). Therefore, the results of this study provide empirical evidence supporting the role of contextual mathematics instruction as an effective approach for developing integrated cognitive and social competencies simultaneously.

From a pedagogical perspective, the findings of this study suggest that mathematics instruction integrating contextual problem exploration and structured collaborative discussion can create meaningful learning environments supporting both conceptual understanding and social engagement. Teachers implementing the Realistic Mathematics Education approach end to facilitate learning experiences encouraging students to actively construct mathematical knowledge while participating productively in collaborative discussions. Recent research also indicates that contextual mathematics instruction supported by structured interaction patterns improves students' learning motivation, engagement, and conceptual understanding more effectively than conventional teacher-centered approaches (Surya & Putri, 2017; Setioningsih et al, 2025).

Despite these important findings, several limitations should be considered when interpreting the results of this study. First, the research was conducted within a limited sample size and school context, which may restrict the generalizability of the findings to broader educational settings. Second, the duration of the intervention was relatively short compared to long-term instructional studies examining sustained effects of contextual learning approaches. Future research is therefore recommended to investigate the long-term impact of the Realistic Mathematics Education approach across different grade levels and mathematical topics using larger and more diverse samples.

Future studies are also encouraged to explore the integration of contextual mathematics instruction with digital learning environments, ethnomathematics perspectives, or technology-supported collaborative platforms to further strengthen students' higher-order thinking development. Such research directions are important because contemporary mathematics classrooms increasingly require instructional approaches capable of integrating conceptual understanding, collaborative competence, and digital literacy simultaneously. Consequently, the Realistic Mathematics Education approach represents a promising instructional framework for supporting the development of critical thinking and collaborative skill as essential components of twenty-first-century mathematics learning environments.

Conclusion

The findings of this study demonstrate that the implementation of the Realistic Mathematics Education approach produced a statistically significant multivariate effect on students' critical thinking and collaborative skills in mathematics learning after controlling for their initial abilities. These results confirm that contextual problem exploration combined with structured collaborative learning activities effectively

supports the simultaneous development of cognitive and social competencies in mathematics classrooms. The large multivariate and univariate effect sizes further indicate that the intervention contributed substantially to meaningful improvements in students' higher-order thinking engagement and collaborative participation, highlighting the strong pedagogical impact of contextual mathematics instruction compared to conventional learning approaches.

These findings extend previous research on Realistic Mathematics Education by providing empirical evidence that this approach improves conceptual understanding and strengthens integrated higher-order thinking as well as collaborative competencies as interconnected learning outcomes required in contemporary mathematics education. From a theoretical perspective, the results support the principle of progressive mathematization and the role of contextual learning environments in facilitating students' active knowledge construction through meaningful interaction. From a practical perspective, the study provides evidence that integrating contextual mathematical problems with structured collaborative activities can create productive learning environments that promote reasoning ability and social interaction simultaneously, making the Realistic Mathematics Education approach a relevant instructional alternative for supporting twenty-first-century mathematics learning competencies.

Despite these contributions, the findings should be interpreted with caution due to the limited sample size and the specific educational setting in which the study was conducted. Future research is therefore recommended to involve larger and more diverse participant groups across different grade levels and learning contexts to strengthen the generalizability of the results. Further investigations integrating longitudinal intervention designs, classroom interaction analysis, technology-supported learning environments, or ethnomathematics perspectives are also suggested to explore more deeply how contextual mathematics instruction contributes to the sustained development of students' critical thinking and collaborative competencies in diverse mathematics learning environments.

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