Indonesian Journal of
Mathematics and Natural Sciences Education
p-ISSN: 2721-172X e-ISSN: 2721-1746
Vol. 6 No. 2 Th 2025; Hal 159-170
http://mass.uinkhas.ac.id DOI: 10.35719/mass.v6i2.218

Mathematical Communication Skills in Realistic Mathematics Education Using Algebra Tiles on Quadratic Factorization

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Abstract

This qualitative descriptive study aimed to explore students' mathematical communication abilities in discovering the concept of quadratic factorization through Realistic Mathematics Education (RME) using algebra tiles. Conducted at SMA Bustanul Mubtadiin Pamekasan with 24 tenth-grade students as subjects, the research focused on three aspects: the implementation of RME-based learning with algebra tiles, students' written mathematical communication, and students' oral mathematical communication. Data were collected through observation, tests, and interviews, and analyzed using the interactive model of Miles, Huberman, and Saldana. The findings revealed that RME facilitated students' gradual understanding of quadratic factorization, transitioning from contextual problems to abstract concepts. Students demonstrated initial strengths in identifying known information and creating visual models in written communication but showed difficulties in explaining strategies and drawing conclusions. In contrast, students' oral communication was more developed, especially in expressing problem-solving strategies. These results highlight RME's effectiveness in supporting visual and procedural aspects of mathematical communication, though further reinforcement is needed to improve students' reflective and comprehensive expression. However, this study is limited by its small sample size within a single school and its narrow focus on qudratic factorization, which may affect the generalizability of the findings.

Key words: Algebra tiles, Mathematical communication Skills, Quadratic factorization, Realistic Mathematics Education (RME).

INTRODUCTION

Communication lies at the core of human interaction and serves as a fundamental pillar in the learning process, including in mathematics education. In this context, mathematical communication is not merely about conveying information, but also about expressing ideas, concepts, and arguments both verbally and in written form (Lubis et al., 2023; Mendrofa, 2021). It enables students to organize and express their knowledge logically and systematically. However, in reality, many students (even those with strong cognitive potential) struggle to communicate mathematical ideas effectively, particularly when dealing with algebraic concepts. Prior empirical findings indicate that students experience severe difficulties in mathematical writing, especially in translating algebraic concepts into formal symbols, where many fail to construct structured arguments and logical explanations on quadratic topics (Humairo, 2022; Sarlina & Alyani, 2021). This systemic deficiency in mathematical communication has been empirically traced back to earlier educational stages. A case study by Rohid et al. (2019) revealed that even at the Junior High School level, a significant majority of Indonesian students perform only at an average level, experiencing profound

DOI: https://doi.org/10.35719/mass.v6i2.218

obstacles when trying to transform narrative text into appropriate mathematical notations and operational structures. If left unaddressed, these foundational communication barriers inevitably persist into Senior High School, where the cognitive load increases. This issue contributes to low motivation toward mathematics as a subject and results in weak conceptual understanding (Sarlina & Alyani, 2021).

The limited development of students' mathematical communication skills is often a consequence of the lack of emphasis on this competence in classroom teaching strategies (Khairunnisyah et al., 2023). In fact, communication in mathematics plays a crucial role in supporting critical thinking and problem-solving (Babe et al., 2023; Muhtadi et al., 2019; Sucipto et al., 2019). Mathematical communication comprises two main components: verbal communication (used to express ideas orally) and written communication (which includes writing in the form of symbols, diagrams, or mathematical narratives) (Humairo, 2022; Lubis et al., 2023). Both components are inherently intertwined with mathematical representation skills, where visual tools (such as algebra tiles) serve as a critical cognitive bridge. Through these visual representations, students can translate spatial, concrete arrangements into formal written expressions and structured oral explanations. Consequently, strong representation skills provide the essential foundation for students to externalize abstract concepts into clear mathematical communication.

To addrres these challenges, the Indonesian adaptation of Realistic Mathematics Education (RME) offers a promising approach. RME emphasizes contextual learning, concrete representation, and student interaction, encouraging meaningful communication throughout the learning process (Manurung et al., 2021; Rasyid, 2019). In this context, concrete media such as algebra tiles can serve as visual tools that help students construct mathematical understanding independently through exploration and discussion.

Previous research has confirmed the effectiveness of RME in improving students' mathematical communication skills (Ahmad & Nasution, 2018; Armania et al., 2018). However, a critical limitation in existing RME literature is that most studies treat mathematical communication as a monolithic skill or rely strictly on aggregate written test scores, without distinctively separating and contrasting oral and written proficiencies during the learning process (Ahmad & Nasution, 2018; Armania et al., 2018; Khairunnisyah et al., 2023). Few studies have focused specifically on the dynamic tension between how students' verbal and written mathematical communication occurs simultaneously during the discovery of quadratic factorization using algebra tiles. Filling this gap is crucial because quadratic factorization often becomes a major stumbling block for students due to its highly abstract nature. Without a deep analysis of the communication process, teachers cannot identify where the cognitive disconnect occurs when students attempt to convert visual concrete representations into formal symbolic language, leading to persistent

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learning difficulties. Thus, this study aims to fill that gap by exploring the processes and quality of student communication during a RME-based lesson involving manipulative media.

METHOD

This study employed a descriptive qualitative approach aimed at portraying the implementation of realistic mathematics instruction using algebra tiles in helping students construct an understanding of quadratic factorization, as well as describing students' mathematical communication skills, both written and oral.

The research subjects consisted of 24 tenth-grade science students from SMA Bustanul Mubtadiin, Pamekasan, who participated in the entire learning process. The study was conducted in June 2024, facilitated by a teacher trained in RME. The researcher acted as an observer and interviewer throughout the process.

Data were collected through observation, written tests, and semi-structured interviews. Observation was used to document students' communication activities and lesson implementation. The written test, integrated into student worksheets, assessed written mathematical communication based on five indicators adapted from the National Council of Teachers of Mathematics (NCTM) framework, while oral indicators focused on verbal expressions during discussions. To ensure data reliability, all instruments and scoring rubrics underwent a validation process through expert judgment by two mathematics education specialists before field implementation.

While this study maintains a descriptive qualitative approach, descriptive statistics in the form of percentages were calculated strictly as a preliminary mapping tool to categorize students' initial performance levels. These percentages do not serve to generalize findings, but rather provide an objective basis for purposive sampling. Finally, semi-structured interviews were conducted with six selected students representing three distinct communication categories: two students from the high-achievement category (meeting T1–T3), two from the moderate category (meeting T1–T2), and two from the low-achievement category (struggling with written formulations), thereby capturing a comprehensive, in-depth understanding of their distinct verbal communication barriers and reasoning. The operational definitions and scoring criteria for each indicator are detailed in Table 1.

RESULT AND DISCISSION

The learning process began with a familiar context: students were asked to imagine arranging a rectangular garden using small bricks. From this scenario, the teacher connected the concept of area to quadratic forms. Algebra tiles were then introduced as tools to represent mathematical structures based on the contextual problem.

The Realistic Mathematics Education (RME) approach facilitated students' reasoning from concrete to abstract. Instead of being given the procedure for factorization directly,

Table 1. Operational Definitions and Scoring Rubric for Mathematical Communication

Code	Indicator	Operational Definition
Written (T)		
T1	Known information	Ability to identify and write down what is known and asked from the problem.
T2	Visual representation	Ability to construct accurate mathematical visuals/drawings
T3	Problem solving strategy	Ability to explain the mathematical strategy or logic used to arrange the tiles
T4	Written prosecude	Ability to write down systematic, algebraic step-by-step calculations.
T5	Drawing Conclusion	Ability to state the final factored form correctly and reflectively on paper
Oral (L)		
L1	Expressing original ideas	Ability to verbally initiate new mathematical insights or ideas during discussion.
L2	Explaining contextual problems	Ability to verbally explain the link between real-world contexts and the algebra tiles.
L3	Explaining strategies	Ability to verbally clarify the steps taken to solve the factorization puzzle.
L4	Communicating result	Ability to verbally present final answers and conclusions clearly to the class.

Scoring Criteria:
- Written indicators (T1–T5) were scored on a scale of 0 to 2, where 2 indicates a complete and correct response, 1 indicates an incomplete response or minor algebraic errors, and 0 indicates no response.
- Oral indicators (L1–L4) were scored similarly: 2 for active and accurate verbal expressions, 1 for hesitant responses or minor conceptual errors, and 0 for remaining silent or non-participation.

student explored quadric expressions by manipulating tiles, recognizing patterns, and constructing the factorization process themselves, This developmental process is illustrated in Figure 1 through the iceberg model, which represents four thinking stages: situational → referential → general → formal (Retta, 2016; Wahyuni & Efuansyah, 2021).

The implementation of the algebra tiles successfully stimulated rich interactive dialogues during group work. To capture how students communicated verbally during the hands-on activity, the following transcript from Group 2 highlights the typical oral interaction observed:

Student A: "*We have to arrange these tiles into a perfect rectangle. Look, we have two big x^2 tiles, three long x tiles, and two small unit tiles*."
Student B: "*If we place the two big tiles side-by-side, the length becomes 2x. But where do we put these negative unit tiles?*"
Student C: "*We need to form a complete rectangle. Try placing the negative tiles at the bottom corner so they balance the configuration. Let's count the vertical and horizontal sides once it's formed*."

This dynamic oral communication allowed students to collectively negotiate the geometric layout of the quadratic components. To systematically analyze these proficiencies, students

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were categorized based on their distinct performance profiles. Table 2 outlines the categorization of students' written mathematical communication skills derived from their individual post-activity worksheets.

Table 2. Categorization of Students' Written Mathematical Communication Proficiency

Category	Indicators Met	Percentage
Category 1	T1 (Identifying Known Information), T2 (Visual Representations)	67%
Category 2	T2 (Visual Representations), T4 (Written Procedures)	16%
Category 3	T1 (Identifying Known Information), T2 (Visual Representations), T3 (Explaining Strategies)	17%
Total		**100%**

Similarly, data gathered via observation protocols regarding students' oral mathematical communication during the RME interactions yielded four distinct performance profiles. Table 3 summarizes the categorization of students' verbal communication skills during classroom discussions.

To unpack the specific cognitive breakdown and illustrate the performance gap across both communication modalities, Figure 2 provides a direct side-by-side comparison of oral versus written indicator achievements.

Table 3. Categorization of Students' Oral Mathematical Communication Proficiency

Category	Indicators Met	Percentage
Category 1	L1 (Expressing Original Ideas), L3 (Explaining Strategies)	16%
Category 2	L2 (Explaining Contextual Problems), L3 (Explaining Strategies)	50%
Category 3	L3 (Explaining Strategies), L4 (Communicating Final Results)	17%
Category 4	L2 (Explaining Context), L3 (Explaining Strategies), L4 (Communicating Final Results)	17%
Total		**100%**

As highlighted in Figure 2, a stark contrast in mathematical communication skills was observed between written and oral modalities, as well as between high-performing students (Category 3 in written tasks) and low-performing students (Categories 1 and 2). In written communication, students exhibited a severe downward trend as tasks shifted from descriptive visuals to abstract formalization. While 100% of the students successfully constructed visual representations (T2) and 83.3% identified known information (T1), achievement sharply declined to 16.7% for both problem-solving strategies (T3) and formal written procedures (T4),

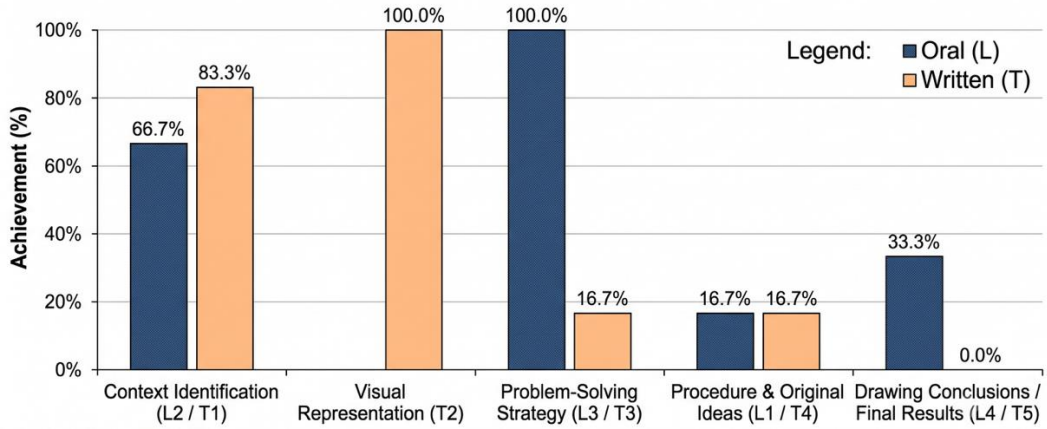


Figure 2. Comparative Analysis of Student Achievement Percentage Across Oral and Written Mathematical Indicators

culminating in an absolute drop to 0% for drawing written conclusions (T5).

The successful students in Category 3 demonstrated a strong ability to execute semiotic transit—the cognitive capacity to seamlessly convert a physical concrete model of algebra tiles into structured visual drawings, and finally into abstract algebraic symbols on paper. As shown in the representative work of Group 2 (Figure 3), these high-performing students did not merely sketch the tiles; they systematically labeled the horizontal and vertical dimensions as factors, wrote clear descriptions of their problem-solving strategies, and concluded with accurate symbolic calculations.

Conversely, the struggling students in Category 1 and 2 remained conceptually trapped in the concrete stage. While they displayed high engagement and successfully manipulated the physical tiles during group work, this physical interaction did not translate into a cognitive footprint on their written worksheets. Their written work stopped entirely at the visual representation level (T2). When required to explain their problem-solving strategies (T3) or write formal procedures (T4), their worksheets revealed severe fragmentation, missing steps, or were left completely blank. During follow-up interviews, a representative student from Category 1 expressed this transition barrier:

Interviewer: "I noticed you arranged the physical tiles correctly in your group, but why did you leave the algebraic procedure blank on your worksheet?"

Student: "I know the form when I hold the tiles and move them around with my friends. It makes sense as a puzzle. But when I sit alone and look at the blank paper, I get confused about how to write the variables (x and x^2) and how to connect the drawing back to the formula."

For these low-performing students, the manipulative media acted merely as a physical puzzle rather than a cognitive bridge to formal symbolic mathematical reasoning. To fully unpack the specific nature of students' struggles, a clear distinction must be made between linguistic (expression-based) and con-

DOI: https://doi.org/10.35719/mass.v6i2.218

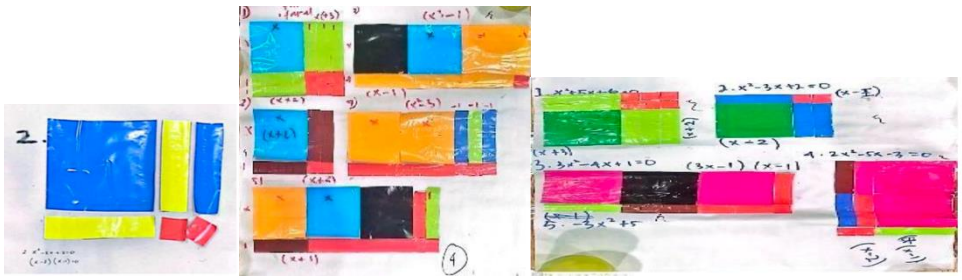


Figure 3. Examples of Students's Work

ceptual (cognitive-based) difficulties:

Linguistic Difficulties: A segment of students understood the geometric layout of the physical algebra tiles but lacked the mathematical literacy and formal vocabulary required to write structured algebraic explanations on paper. During group interactions, they could verbally state the factors correctly. However, when translating this onto worksheets, they failed to construct mathematically sound written equivalence statements, such as failing to connect 〖2x〗^2-3x+2 with (x-2).(x-1), and omitted logical transition words (e.g., "therefore," "based on the vertical and horizontal sides...") necessary to form a coherent mathematical narrative.

Conceptual/Cognitive Difficulties: Students facing deeper structural barriers could not relate the geometric area of the tile arrangement (the product of length and width) to the symbolic process of quadratic factorization. Even with physical tiles, they struggled to comprehend why expressions like 〖2x〗^2-3x+2=0 required a specific combination of positive and negative tiles to construct a valid geometric rectangle. Their worksheets showed arbitrary tile sketches that failed to form mathematically valid closed shapes, directly leading to incorrect and disjointed symbolic expressions. This conceptual impediment closely aligns with the empirical observations of Disasmitowati & Utami (2017), who investigated the use of algebra blocks for factoring quadratic expressions among lower secondary students. Their study revealed that middle-to-low performing students encountered severe cognitive and psychomotor friction when managing negative x coefficients and negative constants, which directly impeded their ability to execute algebraic modeling and transition from visual structures to formal distributive notation. The recurrence of this exact cognitive roadblock in the present study indicates that the struggle to reconcile negative algebraic parameters with physical geometric spaces is a persistent developmental challenge that remains unresolved as students advance to senior high school.

While students' written communication skills were constrained by linguistic and conceptual barriers, their oral mathematical communication painted a completely different picture, showcasing a much higher level of dynamic interaction and verbal confidence. As indicated in Figure 2, 100% of the students successfully achieved the verbal problem-solving

strategy indicator (L3), 66.7% explained contextual problems (L2), 33.3% communicated final results (L4), and 16.7% expressed original ideas (L1). This phenomenon is directly rooted in the instructional nature of the RME framework implemented via algebra tiles.

The RME approach heavily emphasizes contextual exploration, social interaction, and hands-on manipulation. In a collaborative group setting, the tactile nature of algebra tiles creates a low-stakes environment that naturally stimulates informal, spontaneous verbalizations. Students can easily test hypotheses aloud (e.g., "Since there are six small tiles, the two sides must be (x + 2) and (x + 3)") because they can physically move the objects to verify their statements immediately. However, as demonstrated by the contrasting percentages in Figure 2, this rich verbal dialogue does not automatically transfer to individual written communication. Writing requires a higher level of cognitive reflection, internalization, and mastery of formal mathematical syntax—a transition that requires explicit instructional scaffolding which physical manipulation alone cannot provide. This critical transition highlights the asymmetrical relationship between written and verbal modes of mathematical expression, a dynamic that contrasts with the classroom observations of Wilson Arthur (2009). Wilson demonstrated that requiring students to justify their problem-solving processes in writing prior to speaking served as an essential cognitive organizer, allowing them to clarify and solidify their mathematical ideas individually before facing oral presentations. In the context of the present study, the absolute absence of such a reflective written baseline left students highly fluent during the collaborative tactile activity but textually unanchored when the physical scaffolding was removed.

The most significant theoretical concern emerging from this study is the 0% student achievement in drawing written conclusions (T5), compared to 33.3% oral success in communicating final results (L4). This absolute deficit reveals that while RME successfully facilitated the transition from situational to referential thinking via the iceberg model, it fell short of anchoring students into the final formal stage.

Drawing a mathematical conclusion requires a student to step back from the procedural activity of arranging tiles and reflectively summarize the underlying algebraic rule. The 0% success rate in T5 indicates a severe cognitive disconnect: students treated the algebra tiles as an isolated procedure to find an answer, rather than recognizing it as a generalized structural model for quadratic equations. Once the physical tiles were removed or the drawing was completed, students lacked the reflective framework to state why the product of the length and width constituted the definitive factors of the quadratic expression. This finding underscores a critical instructional gap: manipulative media in RME can inadvertently lead to "proceduralized manipulation" if the teacher does not explicitly push students past the physical activity into formal, abstract synthesis.

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These findings expand upon and critically refine existing RME literature. The discovery that students excel visually and orally but stumble severely in written reasoning aligns with the foundational assertions of Ahmad & Nasution (2018) and Armania et al. (2018) who noted that mathematical writing requires explicit, independent training. Furthermore, the collaborative benefits observed mirror the conclusions of Fadhillah & Ahmad (2020) regarding the power of social interaction in RME environments.

However, this study offers a distinct contribution that departs from prior research. While previous RME studies by Khairunnisyah et al. (2023) and Mendrofa (2021) treated mathematical communication as a monolithic skill or relied strictly on aggregate written test scores, this study explicitly unpacks the dynamic tension and developmental asynchronous gap between oral and written proficiencies within a single manipulative lesson. Furthermore, the findings of this study demonstrate that the utilization of concrete media, such as algebra tiles, within the RME framework not only assists students in grasping the concept of quadratic factorization but also optimizes their mathematical communication skills, thereby offering an alternative solution to the recommendation put forward by Rohid et al. (2019) regarding the urgent need for innovative learning activities to stimulate students' mathematical communication. Interestingly, while Rohid et al. (2019) observed that students at the Junior High School level tend to remain passive and frequently make errors when constructing mathematical notations during group discussions, the Senior High School students in this study exhibited a more advanced maturity in their mathematical communication skills. The interactive nature of the RME structure enables high school students to manipulate algebra tiles while fluently articulating logical arguments, both orally during cooperative group work and in written form when symbolizing quadratic structures.

By identifying through Figure 2 that 100% oral strategy communication (L3) can coexist with 0% written conclusion drawing (T5), this research provides a new empirical nuance: it demonstrates that concrete manipulative media can successfully foster immediate verbal engagement while simultaneously failing to leave a lasting cognitive footprint on formal written literacy if not systematically scaffolded. While prior literature, such as Wilson Arthur (2009), recognized that challenging students to express their thinking in both modalities deepens overall understanding and builds mathematical confidence over time, those findings treated written and oral growth as largely parallel trajectories. The precise contribution of this study lies in mapping the immediate, concurrent disparity between perfect verbal engagement and complete failure in formal written syntax within the exact same manipulative experience, proving that immediate verbal confidence can mask deep, unresolved deficits in individual written synthesis.

CONCLUSION

This study demonstrates that the integration of algebra tiles within a Realistic Mathematics Education (RME) framework successfully facilitated the early stages of students' mathematical reasoning, moving them from situational context to referential models. The instructional design, rooted in a real-world garden analogy, was instrumental in anchoring students' initial understanding of quadratic structures through tangible, hands-on manipulation.

However, the tracking of student performance reveals an asynchronous developmental gap between oral and written mathematical communication modalities. On one hand, the collaborative environment and tactile media supported highly dynamic oral communication, allowing 100% of the students to actively explain problem-solving strategies verbally within their groups. On the other hand, this high verbal competence did not translate into a solid cognitive footprint on paper. Students' written mathematical communication suffered from severe linguistic fragmentation and conceptual barriers, leading to an absolute drop to 0% achievement in drawing formal written conclusions.

In conclusion, while the concrete manipulative media successfully facilitated spontaneous verbalizations and visual representations, it was insufficient on its own to anchor students into formal, abstract mathematical synthesis. This highlights a vital instructional implication for RME: to prevent hands-on media from turning into isolated procedural play, teachers must provide explicit, structural scaffolding that actively bridges the gap between concrete manipulation and formal mathematical literacy.

ACKNOWLEDGEMENT

The author expresses sincere gratitude to the principal, mathematics teacher, and all students of SMA Bustanul Mubtadiin Pamekasan for their support and active participation throughout the research process. Appreciation is also extended to fellow lecturers of the Mathematics Education Department at UIN Madura for their valuable input, suggestions, and guidance during the preparation of this article. The author also gratefully acknowledges all parties who contributed to the editing and language refinement of this manuscript, enabling it to be completed properly.

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