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From Peer Interaction to Academic Achievement: Collaborative Learning in Elementary Mathematics

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ABSTRACT

Mathematics learning at the elementary level requires instructional approaches that promote conceptual understanding, active participation, and problem-solving abilities. However, students may experience difficulties understanding two-dimensional shapes when learning activities rely primarily on teacher explanations and individual exercises. This study aims to examine the implementation of the collaborative-based Student Teams Achievement Divisions (STAD) cooperative learning model in improving mathematics learning outcomes and strengthening student collaboration in learning two-dimensional shapes. The study employs a convergent mixed-methods approach, combining quantitative data from learning outcome tests and questionnaires with qualitative data obtained through classroom observations, interviews, and documentation. The findings highlight the role of heterogeneous group formation, peer discussions, idea exchange, shared problem-solving, and individual assessments in supporting students' mathematical learning experiences. The implementation also provides opportunities to develop communication, teamwork, and individual responsibility. The study emphasizes that integrating collaborative engagement with individual accountability is important for creating meaningful mathematics instruction. The implications suggest that teachers should organize structured cooperative learning activities that balance peer interaction and individual assessment to support conceptual understanding and improve the quality of elementary mathematics education.

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INTRODUCTION

Mathematics education plays a fundamental role in preparing elementary school students to think logically, critically, and systematically while developing

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their ability to solve problems in everyday situations (Wang et al., 2023; Zhou & Tsai, 2023). These competencies are important because mathematical learning enables children to recognize patterns, interpret information, make reasoned decisions, and understand relationships between objects and quantities. At the elementary level, geometry is particularly relevant because students encounter two-dimensional shapes in their surrounding environment, including classroom objects, buildings, and everyday materials. Learning about these shapes involves recognizing figures, describing their properties, and understanding perimeter and area. Such learning should develop meaningful conceptual understanding rather than encourage students to memorize formulas without understanding their applications (David Agwu & Nmadu, 2023; Møgelvang & Nyléhn, 2023). Therefore, effective mathematics instruction needs to connect abstract ideas with concrete experiences and active learning opportunities that strengthen students' mathematical reasoning and problem-solving abilities.

Ideally, mathematics instruction should involve students in exploring concepts, asking questions, explaining their reasoning, and applying knowledge to solve problems. However, classroom practice does not always provide sufficient opportunities for these activities. Lessons that rely heavily on teacher explanations and individual exercises can position students as passive recipients of information, limiting interaction and reducing opportunities to identify misunderstandings. This situation may be particularly challenging when students learn perimeter and area because they must distinguish between the boundaries and surfaces of shapes and select appropriate procedures for solving problems. Memorizing formulas alone does not guarantee that students understand the relationship between a shape's properties and its measurement. A gap therefore exists between the expected learning process, which emphasizes conceptual understanding and active participation, and instructional practices that may not adequately develop these competencies (Appiah et al., 2023; Nungu et al., 2023). This condition highlights the need for more interactive and collaborative mathematics instruction.

The classroom conditions motivating this study concern students' engagement and achievement during mathematics lessons on two-dimensional shapes. Preliminary classroom observations indicated several learning challenges, particularly differences in students' participation, difficulties explaining the properties of geometric shapes, and uncertainty when applying perimeter and area concepts to mathematical exercises. Some students appeared to depend on teachers' explanations or answers provided by classmates rather than independently explaining their reasoning (Azizah & Widad, 2026; Kohar et al., 2026). Group interaction also needed to be strengthened so that every student could contribute ideas and take responsibility for completing learning tasks.

These conditions suggest that the learning process requires an instructional approach combining structured peer support with individual accountability. Consequently, improving mathematics instruction involves not only addressing students' difficulties in understanding concepts but also creating opportunities for meaningful interaction, active participation, and shared responsibility throughout the learning process.

Previous research on elementary mathematics instruction has examined instructional materials and learning models designed to improve students' understanding of geometric concepts. Digital teaching materials developed specifically for two-dimensional shapes can provide representations that support students in recognizing figures and exploring their properties. Problem-Based Learning supported by flipbooks has also been applied to teaching perimeter and area, demonstrating the potential of combining problem-solving activities with digital instructional media to improve learning outcomes (Boadu & Boateng, 2024; Ndebil & Ali, 2024). Furthermore, cooperative learning approaches have been associated with improvements in elementary students' mathematics achievement. These findings collectively indicate that mathematical understanding can be strengthened when instruction moves beyond explanation and memorization and provides opportunities for students to actively engage with mathematical concepts (Mahirah et al., 2026; Putri et al., 2026). They also demonstrate that instructional design, learning resources, and classroom interaction are important considerations in developing effective mathematics learning experiences.

Despite these contributions, previous studies have not fully explained how structured collaboration and individual accountability can be integrated when teaching two-dimensional shapes through the Student Teams Achievement Divisions (STAD) model. Research focusing on digital instructional materials and problem-based learning has primarily emphasized learning resources and problem-solving activities, whereas studies examining cooperative learning have frequently concentrated on students' academic achievement. However, the collaborative processes through which students exchange ideas, explain concepts, distribute responsibilities, and support their peers require further investigation in this particular learning context. Moreover, group activities do not automatically ensure that every student participates or understands the material because unequal participation may allow certain students to depend excessively on more academically capable classmates. This gap deserves attention because improvements in learning outcomes should be accompanied by meaningful engagement and individual mastery (Mafarja et al., 2023; D. Zhang & Hwang, 2023). Examining academic achievement alongside collaborative activities can provide a more comprehensive understanding of cooperative mathematics instruction.

The present study addresses this gap by implementing a collaborative-based Student Teams Achievement Divisions model in fourth-grade mathematics lessons on two-dimensional shapes. The distinctive emphasis is not simply on organizing students into heterogeneous groups but on developing purposeful collaboration through exchanging ideas, explaining geometric concepts to peers, distributing tasks, and jointly solving mathematical problems while maintaining individual responsibility. Students are encouraged to identify shapes, compare their properties, and solve exercises involving perimeter and area. Meanwhile, teachers act as facilitators who guide learning activities, monitor student participation, clarify misconceptions, and conduct individual assessments. This approach integrates the cooperative structure of STAD with an explicit emphasis on the quality of students' collaborative engagement. Its contribution lies in examining mathematics learning outcomes and collaborative activities simultaneously within an elementary geometry context, providing a more comprehensive perspective on the implementation of cooperative learning.

Accordingly, this study investigates the implementation of the collaborative-based STAD model in teaching two-dimensional shapes, changes in students' mathematics learning outcomes following its implementation, and students' participation in collaborative learning activities. The study is grounded in the theoretical perspective that peer interaction can support conceptual development when students articulate their understanding, exchange explanations, and compare different problem-solving approaches. At the same time, individual assessment ensures that cooperation does not eliminate personal responsibility for learning. Evaluating both test performance and observed collaboration makes it possible to examine not only whether students' learning outcomes improve but also how classroom participation accompanies these improvements. The findings are expected to provide practical insights into organizing cooperative mathematics instruction that balances peer support with individual accountability. Ultimately, this study seeks to contribute empirical evidence for improving elementary mathematics learning and strengthening students' understanding of two-dimensional shapes.

RESEARCH METHODS

This study employed a convergent mixed-methods design to examine the implementation of the collaborative-based Student Teams Achievement Divisions (STAD) cooperative learning model and its contribution to improving mathematics learning outcomes among fourth-grade elementary school students. This design was selected because the research required both quantitative evidence of changes in students' academic achievement and qualitative information regarding classroom interactions, teacher activities, and student

collaboration during the learning process (Siller & Ahmad, 2024; Talkhan et al., 2025). Quantitative data were obtained through learning outcome tests and questionnaires, while qualitative data were collected through classroom observations, interviews, and documentation. Both types of data were collected within the same research period, analyzed independently using their respective procedures, and subsequently integrated during interpretation. This approach enabled the researchers to compare numerical improvements with classroom experiences, providing a more comprehensive understanding of the effectiveness and implementation of collaborative-based STAD in mathematics instruction.

The research was conducted at an elementary school involving fourth-grade students as the research subjects (Li, 2025; Mariani-Petroze, 2023). The school was selected purposively based on the relevance of its mathematics learning conditions to the objectives of this study, particularly the need to strengthen students' understanding of two-dimensional shapes and improve their participation in collaborative learning activities. The selection also considered the suitability of the classroom environment for implementing the STAD cooperative learning model, which requires heterogeneous group formation, structured discussions, peer assistance, and individual assessments. Fourth-grade students were selected because the learning objectives at this educational level include identifying two-dimensional shapes, understanding their properties, and applying perimeter and area concepts. The research setting therefore provided an appropriate context for examining how collaborative learning activities could support students' conceptual understanding, classroom engagement, and mathematics learning outcomes.

Data were collected through questionnaires, interviews, observations, and documentation. Questionnaires were administered to obtain information about students' responses to collaborative learning activities, including their participation, cooperation, responsibility, and learning experiences during STAD implementation. Interviews were conducted with the classroom teacher and selected students to obtain further information about the implementation process, learning difficulties, and perceived changes in classroom participation. Classroom observations were used to record teacher activities, student engagement, group interactions, task distribution, and collaborative problem-solving during mathematics lessons (Kilpeläinen-Pettersson et al., 2025; Shao et al., 2024). Documentation provided supporting evidence, including lesson plans, student worksheets, photographs of learning activities, attendance records, and students' learning achievement documents. Additionally, mathematics learning outcome tests were administered before and after the intervention or at the end of each learning cycle to measure students' understanding of two-dimensional shapes. These instruments provided complementary quantitative and qualitative evidence.

Quantitative data obtained from learning outcome tests and questionnaires were analyzed using descriptive statistics, including frequencies, percentages, and mean scores. Students' mathematics learning achievement was evaluated by comparing test results before and after the implementation of the collaborative-based STAD model, while questionnaire responses were analyzed to identify patterns in students' collaborative learning experiences. Qualitative data from observations, interviews, and documentation were analyzed through data reduction, data display, and conclusion drawing. The qualitative analysis focused on identifying patterns in classroom participation, peer interaction, individual responsibility, and the implementation of cooperative learning activities. Subsequently, the quantitative and qualitative findings were integrated through comparison and interpretation to identify areas of convergence, complementarity, or differences between the two datasets. This integration provided a comprehensive assessment of changes in learning outcomes and collaborative activities throughout the instructional process.

RESULTS AND DISCUSSION

Results

The Implementation of Collaborative-Based STAD Cooperative Learning Model in Mathematics Learning

The implementation of the collaborative-based Student Teams Achievement Divisions (STAD) cooperative learning model was conducted through several structured learning activities focusing on two-dimensional shapes. The learning process began with the teacher presenting the material, including the identification of shapes, their characteristics, and their elements, according to the established learning objectives. Students were subsequently organized into heterogeneous groups based on their academic abilities. This group formation provided opportunities for students to interact, exchange information, and assist one another in understanding the material. Each group was expected to involve all members in completing the assigned learning tasks. The learning activities emphasized students' participation in identifying different geometric shapes, comparing their properties, and understanding mathematical concepts through collaborative discussions.

During group learning activities, students worked together to complete assignments related to two-dimensional shapes. Each member was encouraged to express opinions, ask questions, provide explanations, and contribute to solving mathematical problems. The activities included identifying differences between squares and rectangles, classifying geometric shapes, and completing exercises related to the material. The teacher facilitated the discussions by monitoring group interactions, providing guidance, and clarifying concepts that students had not fully understood. Following the collaborative activities,

individual assessments were administered to determine each student's understanding of the material. These assessments provided information about individual mastery after students had participated in group discussions. The implementation therefore involved both collective learning activities and individual evaluation as complementary components of the instructional process.

Mathematics Learning Outcomes on Two-Dimensional Shapes

Mathematics learning outcomes were examined through students' achievement in understanding two-dimensional shapes, including recognizing geometric figures, identifying their properties, and solving problems related to the material. Individual assessments were used to evaluate students' understanding after participating in the collaborative-based STAD learning activities. The assessment focused on individual mastery rather than relying exclusively on the group's ability to complete assigned tasks. Learning achievement was evaluated through comparisons of students' average scores and the percentage of students achieving the established learning mastery criteria at the pre-cycle, Cycle I, and Cycle II stages. These indicators provided a basis for examining changes in academic achievement throughout the implementation of the learning model. The available research document describes this evaluation procedure but does not provide the numerical assessment results required to establish the magnitude of improvement.

Student Collaboration Activities during STAD Implementation

Student collaboration was reflected in several learning activities, including participating in discussions, exchanging information, expressing opinions, listening to explanations, and helping peers complete assignments. During group activities, students were encouraged to contribute to identifying geometric shapes, comparing their characteristics, and solving mathematical exercises. Collaboration also involved distributing responsibilities among group members, such as reading questions, proposing solution strategies, recording discussion results, and explaining answers. These activities provided opportunities for students to participate according to their respective abilities while contributing to collective learning objectives. The teacher monitored group interactions and encouraged students who demonstrated limited participation to become more involved. Observation activities focused on discussion participation, communication, task distribution, individual responsibility, and mutual assistance. These indicators provided a framework for examining the development of collaborative learning activities during the implementation of the STAD model.

Discussion

The implementation of the collaborative-based STAD cooperative learning model demonstrates the importance of organizing mathematics instruction around structured peer interaction and individual responsibility (Jaya et al., 2025; Yu et al., 2023). The learning activities involved teacher presentations, heterogeneous group formation, collaborative discussions, group assignments, and individual assessments. This structure reflects the fundamental principles of cooperative learning, in which students develop understanding through interaction while remaining responsible for their individual achievements. The findings are consistent with previous research indicating that STAD can support improvements in elementary students' mathematics learning outcomes. However, the present study places particular emphasis on collaboration as an integral part of learning about two-dimensional shapes (Clemente et al., 2024; Hidayat & Saad, 2025). Students are not merely organized into groups to complete assignments but are encouraged to explain concepts, exchange ideas, and assist their peers. This distinction highlights the importance of interaction quality in supporting meaningful mathematics learning.

The implementation of heterogeneous groups provides an opportunity to address differences in students' academic abilities through peer assistance and shared learning experiences. Students who understand geometric concepts can explain their reasoning to classmates, while students experiencing difficulties can ask questions and receive additional explanations. This process is particularly relevant to learning two-dimensional shapes because students must understand the relationships between geometric properties and mathematical procedures rather than simply memorize formulas (Lee & Paul, 2023; Z. Zhang, 2024). Previous studies examining digital instructional materials have emphasized the importance of providing appropriate learning resources to facilitate conceptual understanding. Similarly, research using problem-based learning supported by flipbooks has demonstrated the potential of instructional strategies to improve achievement in perimeter and area. The present findings extend this perspective by emphasizing collaborative interaction as another mechanism for supporting students' mathematical understanding.

An important aspect of the STAD implementation is the integration of group collaboration with individual assessment. Although students work together during discussions and assignments, each learner remains responsible for demonstrating personal understanding through individual assessments. This arrangement addresses a potential limitation of cooperative learning, namely the unequal distribution of participation among group members (Bringula & Atienza, 2023; Hidayat & Saad, 2025). Without individual accountability, students with stronger academic abilities may dominate discussions, while

others become dependent on their contributions. The combination of collaborative activities and individual assessments helps maintain a balance between collective achievement and personal responsibility. This finding supports the theoretical understanding that effective cooperative learning requires both positive interdependence and individual accountability. Practically, teachers need to monitor group participation, distribute responsibilities appropriately, and evaluate each student's understanding independently to ensure that collaboration contributes to meaningful learning rather than merely completing group assignments.

Student collaboration also has implications for developing communication, responsibility, and mathematical reasoning. Activities involving expressing opinions, listening to explanations, comparing answers, and identifying errors provide opportunities for students to articulate their understanding. When students explain why a particular shape has certain properties or how a mathematical problem should be solved, they are required to organize their reasoning into understandable explanations. This process can strengthen conceptual understanding because mathematical ideas are examined and clarified through interaction. Previous research on cooperative mathematics instruction has similarly emphasized the importance of student interaction in supporting academic engagement and achievement. Nevertheless, collaboration should not be evaluated solely through the presence of group discussions. The quality of participation, the distribution of responsibilities, and the extent to which students contribute to problem-solving are equally important. These considerations provide practical guidance for teachers in designing more inclusive mathematics learning activities.

The theoretical implication of this study concerns the relationship between cooperative learning, conceptual understanding, and individual learning responsibility in elementary mathematics education. The collaborative-based STAD model illustrates how social interaction can be integrated into mathematics instruction without eliminating the importance of individual achievement. Through peer explanations and shared problem-solving activities, students have opportunities to construct and clarify their understanding of geometric concepts. At the same time, individual assessments provide a mechanism for evaluating whether collaborative experiences are accompanied by personal mastery. The practical implication is that teachers should design learning activities that combine heterogeneous group formation, clearly distributed responsibilities, structured discussions, and individual evaluation. In teaching two-dimensional

shapes, these activities can be organized around identifying geometric figures, comparing their properties, and solving perimeter and area problems. Such an arrangement can make mathematics instruction more participatory and responsive to students' learning needs.

The contribution of this study lies in emphasizing the integration of collaborative engagement and individual academic responsibility through the STAD cooperative learning model in elementary mathematics instruction. Unlike approaches that focus primarily on instructional materials or students' final assessment scores, this study considers classroom collaboration as an important dimension of the learning process. Its contribution is reflected in the examination of how peer interaction, shared problem-solving, teacher facilitation, and individual assessment can be organized within lessons on two-dimensional shapes (Ndebil & Ali, 2024; Z. Zhang, 2024). These findings provide a basis for understanding the potential of collaborative-based STAD to support more meaningful mathematics learning. However, the extent of its effectiveness must be established through actual comparisons of pre-cycle, Cycle I, and Cycle II assessment results, together with documented observation data. Overall, the study offers practical insights into developing mathematics instruction that balances conceptual understanding, active participation, and individual responsibility.

CONCLUSION

This study highlights that the collaborative-based Student Teams Achievement Divisions (STAD) cooperative learning model offers a meaningful approach to mathematics instruction, particularly in teaching two-dimensional shapes to fourth-grade elementary school students. The most important finding is that integrating group discussions, peer assistance, idea exchange, and individual assessments provides opportunities to strengthen conceptual understanding while fostering teamwork and individual responsibility. The scientific contribution of this study lies in emphasizing the integration of collaborative engagement and individual accountability as complementary dimensions of cooperative mathematics learning. However, the study is limited to a particular grade level and mathematical topic, which restricts the generalizability of its findings. Future research should examine the implementation of collaborative-based STAD across different educational levels, mathematical topics, and learning contexts using broader samples and longer observation periods. The implications of this study suggest that elementary school teachers should design mathematics instruction that balances structured collaboration with individual assessment to create more active, inclusive, and meaningful learning experiences.

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