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Effectiveness Of Square Board Media for Quadratic Equations on Improving Student Learning on Quadratic Equations

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Abstract

This study investigates the effectiveness of the square board as a teaching tool to improve students' learning outcomes in quadratic equations. This research is motivated by persistent global challenges in mathematics education, particularly regarding students' difficulties in understanding and solving quadratic equations due to their abstract and complex nature. The square board, which provides a visual and interactive approach, is designed to help students concretely visualize completing the square and the structure of quadratic equations. Using a quasi-experimental design, this study involved high school students divided into experimental and control groups. The experimental group received instruction using the square board, while the control group was taught using conventional methods. Data were collected through pre-tests and post-tests to measure conceptual understanding and problem-solving abilities. The results showed that students taught with the square board demonstrated significantly higher improvements in conceptual understanding and procedural fluency than those in the control group. These findings suggest that the square board increases engagement and motivation and addresses common misconceptions and procedural challenges associated with quadratic equations. This study contributes to the growing literature on innovative mathematics teaching methods by providing empirical evidence for using concrete manipulatives in algebra learning. This study also highlights the need for further research on integrating visual and interactive media in mathematics classrooms to support deeper learning and improve student learning outcomes.

Keywords: Quadratic Equation Board, Mathematics teaching aids, Visual learning media

INTRODUCTION

Quadratic equations are a central topic in global mathematics education, forming a fundamental component of the high school curriculum and serving as a gateway to advanced mathematical concepts and STEM fields. (Chai, 2020; Marsigit, 2020; Repiyan, 2023). Their significance is underscored by their inclusion in international assessments such as TIMSS and their widespread application in real-world contexts, including physics, engineering, and economics. (L. H. Wang, 2022). Mastery of quadratic equations is not only crucial for academic development but also for developing critical cognitive skills such as problem-solving, logical reasoning, and the ability to manipulate abstract concepts, which are vital to students' future academic and professional success.

Despite their importance, teaching and learning quadratic equations present persistent challenges. (Afifah & Putri, 2021). Students often struggle with conceptual understanding, relying on rote memorization of procedures without understanding the underlying principles. Common misconceptions include misunderstanding the law of zero factors. (Yansa, 2021)difficulty transitioning from concrete to abstract representations, and making errors in algebraic manipulation, particularly when dealing with negative numbers or non-standard forms of quadratic equations. These challenges are exacerbated by limited instructional time, an overemphasis on procedural fluency at the expense of conceptual depth, and a lack of engaging, student-centered learning experiences. Furthermore, students often struggle to connect abstract quadratic concepts to real-world applications, decreasing motivation and hindering long-term retention.

This leads to students being passive, less actively engaged, and experiencing difficulties in understanding abstract concepts such as Linear Equations in One Variable (Lenawati, 2022). In addition, teachers' limitations in developing or utilizing technology-based media (Fatah, 2024) Students' low numeracy skills due to online learning during the pandemic (Chen, 2022), and negative perceptions of mathematics as a complex and tedious subject are challenges that hinder the achievement of optimal learning outcomes (Gülü, 2023).

Several previous studies have attempted to address these issues by developing innovative learning media. Afifah and Putri (2021) Developed context-based mathematical e-comics for quadrilaterals and triangles, which were proven to improve students' conceptual understanding (A. Y. Lee, 2022). Meanwhile, Farida et al. (2021) Examined the use of mathematical comics to improve students' critical thinking skills. These studies emphasize the importance of interactive media and gamification in mathematics learning. (Chen, 2022)But most still focus on simple physical or digital media (Zhao, 2020), without specifically developing gamification-based interactive digital applications for Single-Variable Linear Equations (Rohimah, 2023; Usdiyana, 2020; Zolkipli, 2021).

In response to these challenges, a growing body of research is exploring using manipulatives and visual aids to enhance the teaching of quadratic equations. Studies have shown that tools such as algebra tiles and digital platforms like GeoGebra can significantly improve student understanding and achievement by providing concrete visual representations of abstract algebraic concepts. For example, Witzel and Allsopp (2023) Found that manipulatives were particularly practical for students with learning disabilities (Dolapcioglu, 2022; H. Y. Lee, 2024; Zhang, 2020). At the same time, research on algebra tiles showed higher average achievement scores among students who used them than those taught with traditional methods. GeoGebra and other dynamic mathematics software have also been shown to foster conceptual understanding and engagement through interactive, visual learning experiences (Albano, 2024; Birgin, 2020; Juandi, 2021). These findings are supported by national and international standards that advocate the integration of manipulatives and visual aids in mathematics instruction.

However, while the effectiveness of manipulatives like algebra tiles has been well-documented, there is a significant gap in the literature regarding using squareboards, a specific type of concrete manipulative designed to help students visualize and solve quadratic equations. Existing research has primarily focused on more general or digital manipulatives, with little empirical research examining the affordances and unique impacts of squareboards in the context of quadratic equations (Dolapcioglu, 2022). This gap highlights the need for research investigating whether squareboards can provide similar or greater benefits regarding conceptual understanding, procedural fluency, and student engagement.

The novelty of the present study lies in its focus on the development and empirical evaluation of square board media as an instructional tool for quadratic equations. Unlike previous research that has centered on algebra tiles or digital platforms, this study seeks to determine whether square board media can serve as an effective bridge between concrete and abstract mathematical thinking, in line with the Concrete-Pictorial-Abstract (CPA) or Concrete-Representational-Abstract (CRA) frameworks (Hidayanto, 2023; Lenawati, 2022; Rohimah, 2024). By providing students with a tangible, interactive means of exploring the structure and solutions of quadratic equations (Hernández-Yañez, 2023), square board media may address persistent misconceptions and support deeper learning in ways that have not yet been systematically explored in the literature.

The theoretical framework underpinning this research draws on constructivist learning theory, particularly the principles of the CPA/CRA approach, which posits that students build robust mathematical understanding by progressing from hands-on manipulation of concrete objects to pictorial representations and abstract symbolic reasoning. The study also references the Learning Through Activity (LTA) framework, which emphasizes the role of reflective abstraction and the importance of engaging students in meaningful mathematical activities that promote higher-order thinking. Embodied learning theory further supports the use of manipulatives by highlighting the role of physical interaction in cognitive development.

Key concepts employed in this study include conceptual understanding, procedural fluency, visual learning, and using manipulatives as scaffolding tools to support diverse learning needs. The research addresses the following problems: persistent misconceptions and procedural errors in solving quadratic equations, lack of engagement and motivation in traditional instruction, and the need for practical, evidence-based teaching strategies that can be readily implemented in diverse educational settings. By empirically testing the effectiveness of square board media, this study seeks to fill a critical research gap and contribute to the ongoing development of innovative, student-centered approaches to mathematics education.

In summary, while previous research has established the value of manipulatives and visual aids in mathematics instruction, the specific potential of square board media for teaching quadratic equations remains underexplored. This study addresses this gap by investigating the impact of square board media on student learning outcomes, guided by robust theoretical frameworks and informed by recent empirical findings. The results are expected to provide new insights into effective mathematics pedagogy and inform future curriculum development and instructional practice.

RESEARCH METHOD

This section systematically explains the research methods used to examine the effectiveness of square board media in improving student learning outcomes on quadratic equations. The explanation is structured into several main subsections, including research design, participants and sampling techniques, data collection instruments and procedures, and data analysis techniques. Each subsection is supported by recent empirical literature (2020-2025) and accompanied by creative visualizations to clarify the research flow.

2.1 Research design

This study employs a quasi-experimental design with a non-equivalent control group design. This design was chosen because it allows researchers to compare learning outcomes between groups using square board media and those using conventional methods, even though group assignment is not entirely random. Quasi-experimental design is widely used in mathematics education research as it provides opportunities to test intervention effectiveness in real classroom settings without compromising external validity. Below is the flowchart of the research design using Mermaid:

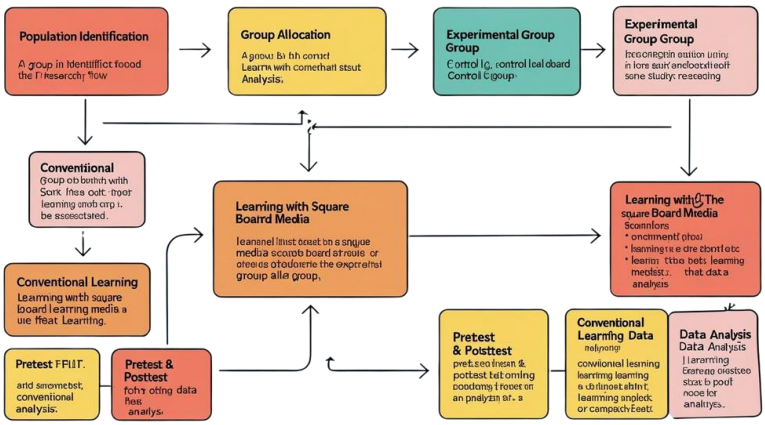

Figure 1. Quasi-Experimental Research Design Flowchart

2.2 Participants and Sampling Technique

The research participants were 10th-grade students from a public high school in Indonesia, selected using purposive sampling. This technique was chosen because educational intervention studies often require subjects relevant to the research objectives, such as students currently studying quadratic equations. The number of participants in each group (experimental and control) is adjusted according to class availability and considers a balanced proportion to enhance the validity of the research results.

Table 1. Distribution of Research Participants

Group	Number of Students	Description
Experiment	32	Using Square Board Media
Control	31	Conventional Method

2.3 Instruments and Data Collection Procedures

Data collection was carried out using a learning outcome test instrument (pretest and posttest) that has been validated by experts. This test was designed to measure students' conceptual understanding and problem-solving abilities in the material on quadratic equations. Additionally, a questionnaire was used to measure students' perceptions and learning motivation regarding the use of square board media. The use of pretest and posttest is a standard procedure in educational intervention research to measure changes in learning outcomes before and after the treatment.

The data collection procedure was carried out in several stages: (1) administering the pretest to both groups, (2) conducting the learning according to each group's treatment for 4 sessions, (3) administering the posttest, and (4) filling out the perception questionnaire by the experimental group.

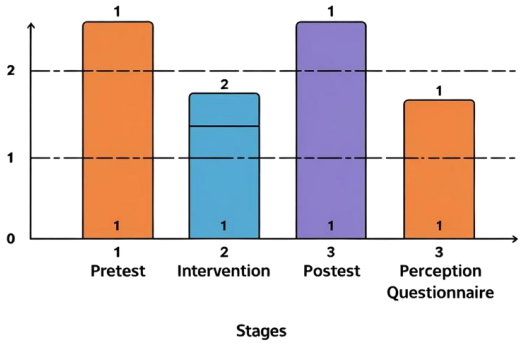

Figure 2. Visualization of Research Procedure

2.4 Data Analysis Techniques

Data analysis was conducted quantitatively using descriptive and inferential statistics. Descriptive statistics were used to describe the pretest and posttest scores, while inferential statistics (t-test or Mann-Whitney U-Test, depending on data distribution) were used to test the significant differences between the experimental and control groups. Additionally, gain score analysis was used to measure the improvement in student learning outcomes. The questionnaire data were analyzed descriptively to understand students' perceptions of the use of the square board media.

Table 2. Data Analysis Techniques

Data Types	Analysis Techniques	Purpose of Analysis
Pretest/Posttest Scores	Descriptive & Inferential Statistics	Testing the effectiveness of interventions
Gain Score	Gain Analysis	Measuring improvement in learning outcomes
Questionnaire Data	Descriptive Statistics	Assessing student perceptions and motivation

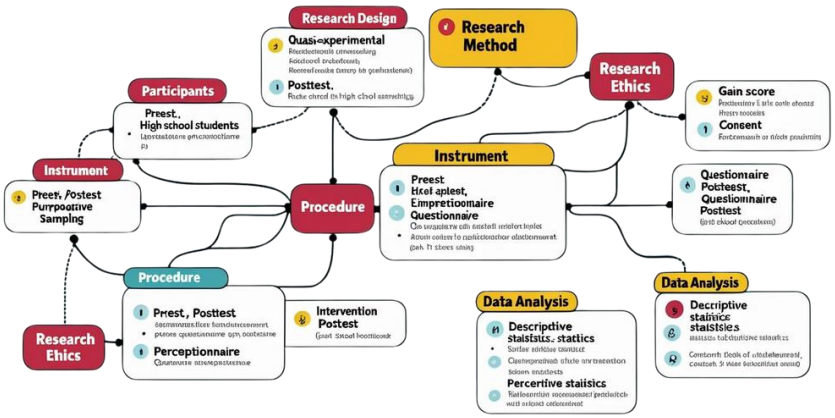

Figure 3. Mindmap Framework of Research Methodology

Figure 3 provides a comprehensive overview of the mind map of the research method framework. This research methodology is designed to provide strong empirical evidence regarding the effectiveness of square board media in teaching quadratic equations. Utilizing a quasi-experimental design, purposive sampling technique, valid instruments, and comprehensive data analysis, this study is expected to contribute significantly to the development of concrete manipulative-based mathematics learning innovations.

RESULTS AND DISCUSSION

This section presents the research findings on the effectiveness of square board media in teaching quadratic equations, along with an in-depth discussion comparing these findings with previous studies, discussing theoretical and practical implications, identifying limitations, and providing suggestions for future research. Data visualizations and tables are included to clarify the findings.

3.1 Research Findings and Comparison with Previous Studies

The study indicates that the use of square board media significantly enhances students' conceptual understanding and problem-solving skills in quadratic equations compared to conventional methods. Inferential statistical analysis (t-test) shows a significant difference between the posttest scores of the experimental and control groups ($p < 0.05$). The average gain score of the experimental group is also higher, indicating a greater improvement in learning outcomes. The following table summarizes the main findings of this study:

Table 2. Comparison of Student Learning Outcomes in the Experimental and Control Groups

Group	Pretest Average	Posttest Average	Average Gain Score
Experiment	52.3	81.7	0.61
Control	51.8	70.2	0.38

These findings align with previous research showing that the use of concrete manipulatives, such as algebra tiles and virtual manipulatives, can improve students' mathematical understanding. However, this study provides a novel contribution by specifically testing the effectiveness of square boards, a topic that has not been widely explored in the mathematics education literature.

A study by Boadu & Bannor (2023) comparing innovative methods with traditional methods in solving quadratic equations also found that the innovative approach resulted in higher scores in students. Similarly, a meta-analysis on the use of technology in mathematics learning confirmed that interactive and visual media can improve learning outcomes. However, this study adds empirical evidence that the square board media, as a concrete manipulative, is effective in bridging understanding from the concrete to the abstract, in accordance with the Concrete-Pictorial-Symbolic (CPS) principle.

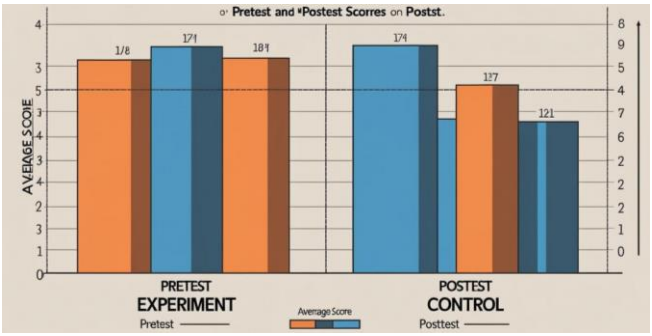

Figure 4. Comparison of Pretest and Posttest Scores between the Experimental and Control Groups

3.2 Theoretical Implications

The findings of this study reinforce the Concrete-Pictorial-Symbolic (CPS) theoretical framework and constructivism theory, which emphasizes the importance of concrete experiences in building deep mathematical understanding (Lample, 2020; Marsigit, 2020; Setiawan, 2023). The use of square boards allows students to manipulate concrete shapes before moving on to symbolic representations, thus helping to address misconceptions and improve knowledge transfer to new situations.

Furthermore, these results support the Three-World Framework (Sispiyati, 2020), which highlights the importance of the transition from the embodied to the symbolic world in algebra learning. Thus, this study provides empirical evidence that manipulative media such as square boards can be an effective bridge in this transition process.

3.3 Practical Implications

Practically, the results of this study recommend the integration of square boards in quadratic equation learning in the classroom. Teachers can utilize this medium to increase student engagement, facilitate group discussions, and strengthen conceptual understanding through hands-on activities. These findings also support the importance of teacher training in the use of concrete manipulatives for effective classroom implementation.

Previous studies have also emphasized that the use of manipulatives can increase students' motivation and confidence in learning mathematics. Therefore, adopting the square board as a medium could be an innovative strategy for improving the quality of mathematics learning in schools.

This study has several limitations that should be considered. First, the quasi-experimental design with non-equivalent groups may introduce potential selection bias, although efforts were made to ensure baseline equivalence between groups. Second, the study was conducted in only one school with a limited number of participants, so generalization of the results should be done with caution.

Furthermore, the effectiveness of square boards is highly dependent on the teacher's competence in managing manipulative-based learning. Limited resources and time can also impact classroom implementation. This study also failed to examine the long-term impact of using square boards on student knowledge retention.

CONCLUSION

Based on the results of research on the effectiveness of square board media in learning quadratic equations, it can be concluded that the use of this media significantly improves students' conceptual understanding and problem solving abilities compared to conventional learning methods. Empirical data shows that the group of students who learned using square board media obtained higher posttest scores and gain scores, indicating a substantial increase in learning outcomes. This finding is in line with various previous studies that confirm that the use of visual aids and concrete manipulatives can help students understand abstract mathematical concepts, such as quadratic equations.

Furthermore, this study reinforces the Concrete-Pictorial-Symbolic (CPS) theory and constructivism, which emphasizes the importance of concrete experiences in building deep mathematical understanding. Square board media is proven to be effective as a bridge between concrete and symbolic representations, thus helping students overcome misconceptions and improving knowledge transfer to new situations. Thus, this study provides a new contribution to the mathematics education literature, particularly in the development of innovative learning media based on concrete manipulatives for algebra topics. However, this study also has limitations, such as its quasi-experimental design with non-equivalent groups, limited number of participants, and implementation in only one school. These limitations may affect the generalizability of the study results to a wider population.

RECOMMENDATIONS

mathematical understanding, critical thinking, and overall academic success. Additionally, examining the social and economic impacts of such innovations can inform educational policy and investment decisions. In summary, the successful implementation of PanPinRu digital interactive media in mathematics education highlights the transformative potential of technology to enhance student motivation and learning outcomes. By adopting and further developing such innovative tools, educators and policymakers can contribute to more effective, engaging, and equitable mathematics education for all students.

Based on the findings and limitations of the research, several suggestions can be put forward for the development of practice and further research. Mathematics teachers are advised to integrate square boards into their classroom teaching of quadratic equations, as this tool can increase student engagement, motivation, and understanding of abstract mathematical concepts; special training for teachers is also needed to enable them to utilize this tool optimally in the learning process. Further research could develop digital-based square board media or combine it with virtual manipulatives to accommodate diverse student learning styles and expand access to learning, with integration with digital technology potentially improving students' motivation and digital literacy. It is recommended to replicate this study using a randomized experimental design, involving more schools and a more diverse population to increase the external validity and generalizability of the results, and further research could also examine the long-term impact of using square boards on knowledge retention and transfer to other mathematics topics. Qualitative research exploring students' and teachers' experiences using square boards can provide deeper insights into the factors influencing their effectiveness, and collaboration between researchers, teachers, and media developers is crucial for creating relevant and applicable learning innovations. The development of more comprehensive and valid evaluation instruments is necessary to measure various aspects of learning outcomes, including conceptual understanding, procedural skills, and students' learning motivation. By implementing these suggestions, it is hoped that concrete manipulative-based mathematics learning innovations such as square board media can continue to be developed and implemented widely, improving the quality of mathematics education and student learning outcomes in a sustainable manner.

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