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The Effect of Problem-Based Learning Assisted by The Desmos Application on Students' Mathematical Ability in the Quadratic Function Material

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ABSTRACT

Students' mathematical ability, particularly in solving quadratic function problems, remains relatively low, as indicated by difficulties in understanding problems and applying appropriate solution strategies. Therefore, this study aimed to examine improvements in students' mathematical ability following the implementation of problem-based learning supported by the Desmos application. This study employed a quantitative approach using a one-group pretest-posttest pre-experimental design involving 32 tenth-grade students. The research instrument consisted of three essay items administered as a pretest and a posttest to measure students' problem-solving performance. The data were analyzed using a paired-sample t-test and N-Gain scores. The results showed that students' posttest scores were higher than their pretest scores, with a statistically significant difference ($p < 0,05$). The N-Gain value was 0.601, which falls within the moderate range, indicating an improvement in students' mathematical performance. The effect size analysis showed a large effect (Cohen's d = 1,49). These findings suggest that problem-based learning assisted by the Desmos application is associated with improved student performance in solving quadratic function problems.

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1. INTRODUCTION

Mathematics is a universal language used to understand and describe phenomena in the world [1]. It is a field of study that is closely associated with calculations, numbers, and formulas. However, mathematics is not merely about numbers and formulas that seem distant from real life. Many mathematical concepts actually originate from everyday problems, which are then modeled mathematically so they can be solved using specific concepts, facts, and systematic procedures. According to Rusefendi [2], mathematics is a deductive science that does not rely on inductive reasoning. It is also a symbolic language and a discipline concerned with constructing orderly patterns and organized structures, beginning with undefined elements, progressing to defined elements, axioms, or hypotheses, and ultimately to propositions. Due to its important role in daily life, mathematics is a compulsory subject in schools.

Nevertheless, mathematics is often perceived as a difficult subject, leading many students to dislike it. As a result, students may become easily bored, less motivated, and reluctant to engage in learning activities, which ultimately affects their learning outcomes [3]. The National Council of Teachers of Mathematics [4] states that the primary goals of mathematics learning are to enable students to communicate using mathematical language, think mathematically, solve problems, make connections among ideas, and develop positive attitudes toward mathematics. Therefore, mathematical thinking ability is an essential competence that every student must possess. This ability includes understanding and solving mathematical problems through reasoning, communication, problem-solving, conceptual connections, and critical and creative thinking skills [5].

Mathematical ability is one of the fundamental skills every student needs. Through this ability, students can think logically, systematically, critically, and creatively in solve various problems, both in academic contexts and in everyday life. Azizah [5] states that mathematical ability refers to students' competence in mastering and applying their skills to solve mathematical problems. In schools, mathematics serves as a foundation for understanding many other disciplines, such as science, economics, technology, and social sciences. Therefore, strong mathematical competence not only helps students achieve high academic performance but also prepares them to face increasingly complex and data-driven future challenges. Mathematical ability encompasses various aspects, including conceptual understanding, procedural fluency, logical reasoning, problem-solving skills, communication using mathematical language, and the ability to represent ideas appropriately. All of these aspects are interconnected and form an integrated framework of mathematical thinking. For example, when students solve a problem, they must first understand the underlying concepts, apply appropriate procedures, reason about the results, and then clearly explain their thought processes. Each student also demonstrates different levels of mathematical ability in problem-solving. Some students can complete problem-solving to the final stage, others can only plan solutions, while some remain at the stage of understanding the problem [6]. Students with high mathematical ability tend to find it easier to solve problems given by the teacher [7].

In this study, mathematical ability is operationally defined as students' competence in solving mathematical problems, which is measured using the following indicators: (1) the ability to understand the problem by identifying known and unknown information; (2) the ability to plan a solution strategy by selecting appropriate concepts or methods; (3) the ability to execute the solution systematically and accurate; and (4) the ability to interpret and conclude the result logically. These indicators align with the assessment instrument used in this study, which consists of three essay items designed to measure students' problem-solving processes across these stages.

However, in reality, many students still struggle in develop their mathematical abilities optimally. This can be observed from low learning outcomes, misunderstandings of mathematical concepts, and the tendency to memorize formulas without understanding their meanings. Various research findings indicate that students’ mathematical understanding remains at a concerning level. According to the Organization for Economic Co-operation and Development [8]'s Program for International Student Assessment (PISA), Indonesian students' performance in mathematics remains below the international average. This condition suggests that mathematics instruction in schools needs improvement, particularly in its approaches, strategies, and learning models, to enhance students’ understanding and skills in mathematics. This problem is also evident at the local level. Based on preliminary observations conducted at MAS Plus Al Ulum Medan, many students experienced difficulties in solving non-routine mathematical problems. Students were generally able to identify given information; however, they struggled to plan appropriate solution strategies and to complete the solution process correctly. In addition, a preliminary test indicated that students’ average scores remained below the minimum mastery criterion (KKM). This finding shows that students’ mathematical ability, particularly in problem-solving, remains low and needs improvement. One contributing factor to this condition is the learning approach that does not sufficiently engage students in meaningful learning experiences. Most classroom instruction remains teacher-centered, with students primarily listening to the teacher's explanations. As a result, students are less able to develop higher-order thinking skills [9].

The low level of students’ mathematical ability must be addressed promptly by implementing learning strategies that actively engage students in the classroom. One possible solution is to apply appropriate instructional models. The learning models employed by teachers should encourage students’ critical thinking activities so that they not only become capable of solving problems but also understand the problems and the meaning behind the solution processes. Thus, improving mathematical ability is not only about achieving correct final answers but also about how students understand, reason, and apply mathematical concepts in various real-life situations. Traditional lecture-based methods, still widely used in schools, often make students passive and less able to connect mathematical concepts to real-life contexts. In fact, mathematics instruction should adopt a contextual approach so that students can develop deeper conceptual understanding and apply mathematical concepts in various everyday situations [25].

One learning model that supports students in improving their mathematical abilities is problem-based learning. This model is grounded in real-life problems encountered in everyday situations that require solutions and problem-solving processes [10]. Problem-based learning uses authentic problems as the starting point of instruction. Therefore, students are not immediately provided with formulas or step-by-step procedures as in traditional teaching; instead, they are encouraged to understand and solve problems closely related to their daily lives. Problem-based learning is an instructional model that involves students in solving problems through the stages of the scientific method, enabling them to develop positive attitudes, acquire knowledge related to the problem, and simultaneously build problem-solving skills. It is not designed to help teachers transmit as much information as possible to students. Rather, it is developed to help students enhance their thinking abilities, problem-solving skills, and intellectual competencies, learn various adult roles through engagement in real or simulated experiences, and become independent learners [9]. Problem-based learning is an problem-based model that encourages students to be active and engage in critical thinking when addressing problems [11]. In this learning approach, the teacher acts as a facilitator rather than the sole source of information. The teacher presents challenging problems, and students work individually or collaboratively to analyze, investigate, discuss, and determine the best possible solutions. Through this process, students not only learn the subject matter but also develop the ability to think like problem solvers. Problem-based learning is also rooted in cognitive psychology; therefore, instruction focuses not merely on what students are doing but, more importantly, on what they are thinking while engaging in learning activities [12].

This learning model helps students improve their mathematical abilities by encouraging logical and critical thinking to understand problems and find appropriate solutions, and by connecting mathematical concepts to real-life situations so students can more easily grasp their meaning. It also trains students' communication skills, as they are required to explain their ideas, solution steps, and reasoning to peers or teachers, and to collaborate and respect others' opinions during group discussions. Through this learning approach, students are expected to understand both the problems and the solutions applied in solving the given tasks. In addition to instructional models, technology also plays an important role in improving students' mathematical abilities. The use of technology has been proven to create more interactive, engaging, and relevant learning experiences that align with the characteristics of today's digital generation [13]. According to [14], technology-based interactive learning can substantially enhance students' mathematical abilities through exploration, data analysis, and reflection supported by realistic simulations. One technology that can be used in mathematics learning is the Desmos application.

Desmos is a web-based platform that allows users to create mathematical graphs [15] and provides interactive tools accessible through both websites and mobile applications on Android and iOS devices [16]. It can be utilized to support learning activities, particularly in algebra and calculus [17]. Several studies have shown that using Desmos can improve students' mathematical abilities. Therefore, integrating Desmos within problem-based learning is expected to create a more effective and meaningful learning process.

Based on the above background, the research question of this study is: (1) does the implementation of problem-based learning assisted by the Desmos application improve students' mathematical ability? (2) is there a significant difference between students' pretest and posttest scores after the implementation of the learning model? This study hypothesizes that students' posttest scores will be significantly higher than their pretest scores following the implementation of problem-based learning supported by the Desmos application.

2. METHOD

This study employed a quantitative, pre-experimental design. In pre-experimental research, the results are not fully influenced by control of independent variables; therefore, the researcher used only one experimental class with a one-group experimental design. The population of this study consisted of all tenth-grade students of MAS Plus Al Ulum Medan. The sample was selected using purposive sampling, resulting in a total of 32 students, comprising 10 male and 22 female students. The researcher measured changes resulting from the instructional treatment using a one-group pretest–posttest research design. The research design is illustrated in Figure 1 as follows:

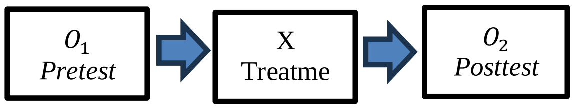

Figure 1. One-Group Pretest–Posttest Research Design

Description:

O_1 : Pretest score

X : Problem-based learning assisted by the Desmos application

O_2 : Posttest score

The pretest and posttest were administered using different sets of questions with equivalent levels of difficulty. The number of questions used for both the pretest and posttest consisted of three essay items. Prior to developing the test instruments, the researcher prepared test blueprints, scoring rubrics, item numbers, and answer keys for each question administered. The data obtained from the pretest and posttest were analyzed using a *t*-test and further calculated using the N-Gain score. The purpose of using the N-Gain score in this study was to determine the effectiveness of the treatment provided [18]. Table 1 presents the classification of N-Gain scores.

Table 1. Classification of N-Gain Scores

N-Gain Score	**Category**
$\boldsymbol{g > 0,7}$	High
$\boldsymbol{0,3 \le g \le 0,7}$	Moderate
$\boldsymbol{g < 0,3}$	Low

Based on Table 1, an N-Gain score greater than 0.7 is classified as high, an N-Gain score greater than or equal to 0.3 and less than or equal to 0.7 is classified as moderate, and an N-Gain score less than 0.3 is classified as low.

3. RESULTS AND DISCUSSION

3.1. Results

The learning outcomes related to students' mathematical abilities in the quadratic function material, delivered through problem-based learning assisted by the Desmos application, are presented in the following figure.

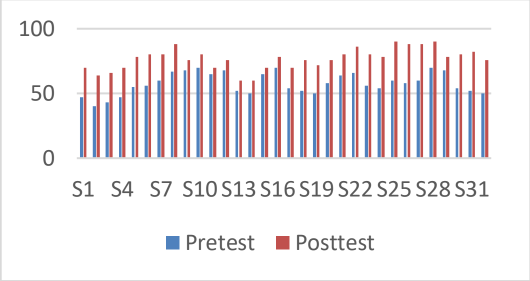

Figure 2. Students' Pretest and Posttest Scores

Based on the data above, it can be seen that the lowest pretest score was 40, while the highest was 70. In the posttest results, the lowest score increased to 60, and the highest score reached 90. Based on these results, a normality test was conducted to determine whether the pretest and posttest data were normally distributed. The results of the normality test are presented in the following table.

Table 2. Normality Test Result

	Kolmogorov–Smirnov[a]			**Shapiro–Wilk**		
	Statistic	df	Sig.	Statistic	df	Sig.
Pretest Scores	0.118	32	0.200*	0.953	32	0.177
Posttest Scores	0.150	32	0.064	0.953	32	0.171

This is a lower bound of the true significance.
[a] Lilliefors Significance Correction

Based on the results shown in Table 2, both the pretest and posttest data have significance values greater than 0.05, indicating that the data are normally distributed. The next step was to conduct a *t*-test to determine whether there was a difference in students' scores before and after the instructional treatment was implemented. The results of the *t*-test are presented in the following table.

Table 3. Result of t-test

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	Nilai Pretest - Nilai Posttest	-18.969	7.798	1.378	-21.780	-16.157	-13.761	31	.000

Based on the t-test results, the significance value was less than 0.05, indicating a significant difference in students' scores before and after implementing problem-based learning on the quadratic function material using the Desmos application. The N-Gain score falls into the moderate category with a value of 0.601.

3.2. Discussion

The results of this study indicate that students' mathematical ability, particularly in solving quadratic problems, improved after the implementation of problem-based learning assisted by the Desmos application. This improvement is reflected in the increase in posttest scores compared to pretest scores, as well as the moderate N-Gain classification. These findings suggest that the learning intervention was associated with better student performance on the essay-based test. However, it should be noted that this study employed a one-group pretest-posttest design. Therefore, the results indicate improvement after the intervention, but they do not provide sufficient evidence to claim that the observed improvement was solely caused by the integration of problem-based learning and the Desmos application. Other factors, such as students' prior knowledge, increased familiarity with the test format, or general learning progression, may also have contributed to the improvement.

The improvement observed in this study is specifically related to students' performance on quadratic-function problem-solving tasks, as measured by the essay test. These tasks required students to demonstrate their ability to understand problems, plan solution strategies, execute procedures, and conclude results. During the learning process, students engaged in activities such as exploring graphs using Desmos, discussing solutions in groups, and presenting their findings. These activities may have supported the development of the problem-solving process; however, since the instrument consisted of three assay items, the findings should be interpreted within the scope of test performance rather than broader constructs such as communication skills, motivation, or general mathematical reasoning. The implementation of problem-based learning in this study followed several structured stages, including problem orientation, group organization, guided investigation, presentation of results, and evaluation. During these stages, students actively engaged in solving contextual problems involving quadratic functions. Using the Desmos application allowed students to visualize changes in quadratic graphs by manipulating parameters, helping them better understand the relationship between algebraic expressions and graphical representations. This combination of structured problem-solving and visual exploration may explain the observed improvement in students' test performance.

These findings are consistent with previous studies, although with some contextual differences. For example, Astuti et al. [19] reported that problem-based learning supported by Desmos improved students' mathematical reasoning and self-determination. While that study focused on reasoning and affective aspects, the present study specifically measured problem-solving performance through essay tests on a quadratic function. Similarly, Nisa et al. [20] found that Desmos uses supported mathematics teaching by enhancing visualization, particularly for teachers at the vocational school level. Although their studies focused on teacher training rather than student outcomes, both highlight Desmos's role in facilitating conceptual understanding through visualization. In addition, Lubis et al. [17] demonstrated that Desmos-based interactive learning media improve student learning outcomes in quadratic function material at the junior high school level. Machado et al. [21] reported that the Desmos platform promotes active learning in geometry by fostering student independence. A similar statement was also made by Dy [22], who noted that the use of

Desmos can improve understanding of graphs, making learning activities easier and more accessible. Further benefits of Desmos in learning were highlighted by Cooper [23], who reported that Desmos activities are designed to create an interactive and engaging learning environment, thereby fostering students' ownership of their learning. Meto [24] also found that this innovative graphing tool (Desmos) significantly enhances students' learning outcomes in understanding circle equations. This is closely aligned with the present study in terms of topic (quadratic function) and outcome (learning result), although the educational level and research design differ. These comparisons indicate that the effectiveness of Desmos-supported learning may depend on the context, learning design, and measured outcomes.

This study has several limitations that should be considered when interpreting the findings. First, the use of a one-group pretest-posttest design without a control group limits the ability to establish a causal relationship between the intervention and the observed improvement. Second, the sample size was relatively small and limited to one class, which may affect the generalizability of the results. Third, the measurement of students' mathematical ability was based on three essay items that primarily captured problem-solving performance and may not fully represent broader mathematical competencies, such as communication and reasoning.

Despite these limitations, this study provides several practical implications for mathematics teachers. First, integrating problem-based learning with the Desmos application can support students' understanding of quadratic functions, particularly in connecting algebraic and graphical representations. Teachers are encouraged to design contextual problems that require students to explore relationships between parameters (a, b, and c) and graph characteristics. Second, effective implementation requires careful planning of classroom organization. Group work with 3-4 students per group is recommended to ensure participation. Time allocation should also be structured appropriately, for example: problem orientation (10-15 minutes), group investigation (30-40 minutes), and presentation and reflection (15-20 minutes).

Third, teachers should provide scaffolding prompts to guide students during problem-solving activities, such as: "What information is given in the problems?"; "What strategy can you use to solve it?"; "How does changing the value a,b, or c affect the graph?"; or "Can you explain your solution in your own words?". These prompts can help students develop systematic problem-solving skills and improve their performance on mathematical tasks.

4. CONCLUSION

This study indicates that the implementation of problem-based learning assisted by the Desmos application is associated with an improvement in students' mathematical performance, particularly in solving quadratic function problems. The findings highlight the potential of integrating problem-based learning with technology to support students' engagement in problem-solving activities and to facilitate a more meaningful understanding of mathematical concepts. The implications of this study suggest that mathematics teachers can utilize problem-based learning combined with the Desmos application as an alternative instructional approach to support students' learning, especially in topics that require visualization, such as quadratic functions. The use of interactive technology can help students explore mathematical relationships more effectively and encourage active participation in the learning process. However, this study has several limitations. The use of a one-group pretest-posttest design limits the ability to establish causal relationships between the intervention and the observed improvement. In addition, the study involved a relatively small sample from a single school, which may restrict the generalizability of the findings. Furthermore, the measurement focused on students' performance on a limited number of essay items, which may not fully represent broader aspects of mathematical ability. Future research is recommended to employ a more rigorous design, such as a quasi-experimental design with control groups, large sample sizes, and multiple school settings, to strengthen the validity and generalizability of the findings. In addition, further studies should explore other dimensions of mathematical ability, including conceptual understanding, procedural fluency, retention, and students' attitudes or motivation toward mathematical learning. Overall, this study contributes to the field of mathematics education by providing empirical evidence on the use of problem-based learning, supported by the Desmos application, as a practical approach to support students' learning. For the general public, particularly educators, this study offers insights into how technology-integrated learning can be implemented to create more interactive and meaningful mathematics instruction.

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