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The Effect of Differentiated Learning on Understanding the Concept of Quadratic Functions at MAN 2 Palu City

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A B S T R A C T

Students' understanding of mathematical concepts, particularly in quadratic functions, is still relatively low because the material requires abstract and representational thinking skills. Therefore, an adaptive learning approach that accommodates students' learning characteristics is needed. This study aimed to determine the effect of differentiated instruction on students' understanding of quadratic function concepts in class X of MAN 2 Palu City. This study employed a quantitative approach with a quasi-experimental method using a One-Group Pretest-Posttest Design. The research sample was selected through purposive sampling. The research instrument consisted of an essay test on quadratic function conceptual understanding that had been validated by experts. Data were analyzed using descriptive statistics and inferential statistics through the Paired Sample t-Test. The results showed that the average pretest score of students was 77.17, while the average posttest score increased to 88.17 after the implementation of differentiated instruction. The hypothesis testing results indicated a significance value of less than 0.05, showing a significant difference between pretest and posttest scores. In addition, the Cohen's d effect size indicated a very large effect category. Thus, differentiated instruction can be considered an effective learning approach to improve students' understanding of quadratic function concepts.

1. Introduction

Mathematics is one of the scientific disciplines that plays an important role in developing students' logical, analytical, systematic, and critical thinking skills (Sapitri, 2026). In the context of education, mathematics learning is not only oriented toward procedural mastery but also toward the ability to understand concepts deeply as a foundation for problem-solving and rational decision-making (Rosjanuardi & Juandi, 2023). However, various studies have shown that students' understanding of mathematical concepts is still relatively low, especially in topics

that are abstract and require complex mathematical representation skills (Nafsy et al., 2022)

One of the mathematics topics that often causes difficulties for students is quadratic functions (Azmi & Yunita, 2022). This material requires students to understand the relationships among mathematical representations, such as algebraic forms, tables, graphs, and contextual interpretations (Syarifuddin et al., 2022). Students are not only expected to perform computational procedures but also to understand the relationship between function coefficients and the characteristics of the resulting graphs. A good understanding of quadratic functions enables students to model various contextual problems in everyday life, such as object motion trajectories and optimization problems (Syarifuddin et al., 2025). However, in the learning process, many students are still unable to understand quadratic function concepts optimally (Azmi & Yunita, 2022). These difficulties can be observed in students' abilities to determine quadratic function forms, draw graphs, and relate coefficient values to graph characteristics (Dakhi et al., 2025). This condition indicates that students' conceptual understanding of quadratic function material still needs to be improved through more effective and meaningful learning approaches (Nugraha et al., 2025).

The low level of students' mathematical conceptual understanding cannot be separated from learning processes that still tend to be teacher-centered, causing students to receive information passively rather than actively constructing conceptual understanding through exploration and active involvement in mathematics learning (Hayati & Asmara, 2021). In such learning environments, students tend to receive information passively instead of building knowledge through exploration and learning interaction processes (Ade Sintia Wulandari, 2022). As a result, mathematics learning is often oriented toward mastering problem-solving procedures rather than developing conceptual understanding.

As an alternative to conventional learning, differentiated instruction emerges as an approach oriented toward students' learning needs (Pebriyanti, 2023). This approach emphasizes the adjustment of learning content, processes, and products based on students' readiness, interests, and learning profiles. Therefore, students obtain more adaptive learning experiences and have greater opportunities to understand concepts optimally according to their individual learning characteristics (Nasser et al., 2024)

Various studies have shown that differentiated instruction positively affects students' mathematics learning processes and outcomes (Muslimin et al., 2022). Differentiated instruction has been proven to improve learning outcomes, mathematical problem-solving abilities, and students' engagement in learning through adjustments to students' readiness levels and learning characteristics (Sitorus et al., 2023). The integration of differentiated instruction with innovative learning models also indicates that adaptive learning can help students develop mathematical thinking strategies more effectively (Herwina, 2021). However, most previous studies have mainly focused on mathematical problem-solving abilities and general mathematics learning outcomes. Other studies also revealed that the integration of differentiated instruction with innovative learning models

significantly improves students' mathematical abilities (Mayang et al., 2026), and positively affects mathematical problem-solving abilities through adjustments to students' learning characteristics (Ayu & Pratiwi, 2024).

Based on various previous studies, differentiated instruction is known to positively influence students' mathematics learning processes and outcomes. (Ayu & Pratiwi, 2024) showed that differentiated instruction effectively improves students' mathematical problem-solving abilities through learning adjustments based on students' learning needs. Previous studies also revealed that problem-based differentiated instruction positively affects students' mathematical problem-solving abilities because the learning process is adjusted to students' readiness levels, enabling students to develop problem-solving strategies more optimally (Rohim et al., 2024). In addition, (Nur & Rahmawati, 2024) found that differentiated instruction integrated with the Problem Based Learning model improves students' problem-solving abilities in relation and function material. Furthermore, (Mulbar & Upu, 2025) reported that the implementation of differentiated instruction effectively improves students' mathematical problem-solving abilities. (Soliha, 2025) also stated that the implementation of differentiated instruction assisted by GeoGebra improves students' mathematical problem-solving abilities.

Several previous studies published in the Journal of Educational Sciences also reported that differentiated instruction contributes positively to students' learning engagement and academic achievement. Research by Musfita et al. (2025) showed that differentiated learning modules improved students' understanding and learning outcomes through learning activities adjusted to students' readiness, interests, and learning profiles. In addition, Nofitasari & Nugraha (2025) found that differentiated instruction created a more inclusive and student-centered learning environment that increased students' motivation and participation during the learning process. Other studies also emphasized that differentiated learning supports flexible instruction and accommodates students' diverse learning needs effectively (Rosidah & Minsih, 2026). These findings indicate that differentiated instruction has strong potential to improve learning quality and students' conceptual understanding across various educational contexts.

Nevertheless, most previous studies have primarily focused on mathematical problem-solving skills and general mathematics learning outcomes. Studies examining the effect of differentiated instruction on students' conceptual understanding, particularly in quadratic function material at the Madrasah Aliyah level, are still relatively limited. In fact, quadratic functions require strong representational and mathematical conceptual connection abilities, making it necessary to implement learning approaches that accommodate students' diverse learning characteristics. In addition, studies conducted in the context of Madrasah Aliyah in Palu City are still rarely found. Therefore, this study was conducted to examine the effect of differentiated instruction on students' understanding of quadratic function concepts in class X of MAN 2 Palu City.

2. Methodology

This study employed a quantitative approach with a quasi-experimental research design to examine the effect of the implementation of differentiated instruction on students' understanding of quadratic function concepts. The research design used was the One-Group Pretest-Posttest Design, which involves measuring students' initial abilities before the treatment (pretest) and measuring their final abilities after the treatment (posttest) in the same group. This design was used to identify changes in students' conceptual understanding after the implementation of differentiated instruction.

The population in this study consisted of all tenth-grade students of MAN 2 Palu City. The research sample was determined using a purposive sampling technique based on the consideration of students' initial ability characteristics. Before determining the sample, a pretest was administered to four classes to identify students' initial abilities in quadratic function material. Based on the pretest results, one class with relatively homogeneous initial ability characteristics was selected as the experimental class. The selected class was then given treatment in the form of differentiated instruction and concluded with the administration of a posttest to determine changes in students' conceptual understanding after the treatment was implemented.

The research instrument used was an essay test on quadratic function conceptual understanding developed based on indicators of mathematical conceptual understanding. These indicators included students' abilities to restate concepts, represent concepts in various mathematical representations, connect concepts, and apply concepts in solving mathematical problems. Before being used in the research, the instrument was first tested for validity. Instrument validity was carried out through content validity using expert judgment.

The research data were analyzed using descriptive statistics and inferential statistics. Descriptive statistics were used to describe the characteristics of the pretest and posttest data, including mean scores, standard deviations, minimum scores, and maximum scores. Furthermore, the normality test was conducted using the Shapiro–Wilk test because the research sample size was relatively small. The normality test results showed that the pretest data had a significance value of 0.246 and the posttest data had a significance value of 0.132. Since both significance values were greater than 0.05, the data were considered normally distributed. Therefore, hypothesis testing was conducted using the Paired Sample t-Test to determine the difference between pretest and posttest scores after the implementation of differentiated instruction.

3. Result and Discussion

This study aimed to determine the effect of differentiated instruction on students' understanding of quadratic function concepts in class X of MAN 2 Palu City. The research data were obtained through the administration of a pretest before the

treatment and a posttest after the implementation of differentiated instruction. Before the implementation of differentiated instruction, the teacher identified students' learning readiness through pretest results and classroom observations. Based on the identification results, students were grouped according to their level of learning readiness and learning characteristics. Students with higher initial abilities were provided with exploratory activities related to the relationship between quadratic coefficients and graph characteristics, while students with lower abilities received more structured guidance through step-by-step exercises, visual representations, and teacher scaffolding. In addition, the learning process was adjusted to students' learning profiles through the use of graphs, contextual problems, and collaborative discussions to help students understand quadratic function concepts more meaningfully. The results of the descriptive statistical analysis of students' pretest and posttest scores are presented in Table 1.

Table 1. Descriptive Statistics

Variable	N	Minimum	Maximum	Mean	Std. Deviation	Variance
Pretest	36	69	86	77.17	4.925	24.257
Posttest	36	81	97	88.17	4.718	22.257
Valid N (listwise)	36					

Based on Table 1, it can be seen that the average pretest score of students was 77.17 with a minimum score of 69 and a maximum score of 86. After the implementation of differentiated instruction, the average posttest score increased to 88.17 with a minimum score of 81 and a maximum score of 97. These findings indicate an improvement in students' understanding of quadratic function concepts after the treatment was administered.

In addition, the increase in the minimum score from 69 to 81 indicates that the improvement in learning outcomes did not only occur among high-achieving students but also among students with relatively lower abilities. The standard deviation value in the pretest was 4.925, while in the posttest it decreased to 4.718, indicating that the distribution of students' scores became more homogeneous after the implementation of differentiated instruction. This finding suggests that differentiated instruction has the potential to reduce learning disparities among students with different academic abilities. Before conducting hypothesis testing, a normality test was first carried out using the Shapiro–Wilk test. The results of the normality test are presented in Table 2.

Table 2. Normality Test

		Kolmogorov-Smirnov			Shapiro-Wilk		
	Class	Statistic	df	Sig.	Statistic	df	Sig.
Result	Pretest	.087	36	.200*	.962	36	.246
	Postest	.117	36	.200*	.953	36	.132

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

Based on the normality test results in Table 2, the significance value of the pretest was 0.246 and the posttest was 0.132. Since both significance values were greater than 0.05, the research data were normally distributed. Therefore, hypothesis testing was conducted using the Paired Sample t-Test. The hypothesis testing using the Paired Sample t-Test was conducted to determine the difference between students' pretest and posttest scores after the implementation of differentiated instruction. The results of the test are presented in Table 3.

Table 3. Paired Sample t-Test

Pair	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference (Lower)	(Upper)	t	df	Sig. (2-tailed)
Pretest-Posttest	-11.000	1.512	0.252	-11.512	-10.488	-43.655	35	< 0.001

Based on the results of the Paired Sample t-Test presented in Table 3, the significance value obtained was less than 0.05. Therefore, the null hypothesis was rejected and the alternative hypothesis was accepted. This indicates that there was a significant difference between students' pretest and posttest scores after the implementation of differentiated instruction. The mean difference value of -11.000 indicates that the average posttest score increased by 11 points compared to the pretest score. Thus, differentiated instruction had a positive effect on students' understanding of quadratic function concepts. To determine the magnitude of the effect of differentiated instruction on students' understanding of quadratic function concepts, an effect size test was conducted using Cohen's d. The calculation results showed a Cohen's d value of 7.28, which falls into the category of a very large effect. This finding indicates that differentiated instruction provided not only statistical significance but also strong pedagogical significance in improving students' conceptual understanding of quadratic functions.

The findings of this study indicate that the implementation of differentiated instruction positively influenced students' understanding of quadratic function concepts in class X of MAN 2 Palu City. The improvement was reflected in the increase in the average student score from 77.17 in the pretest to 88.17 in the posttest, as well as the results of the Paired Sample t-Test, which showed a significant difference between students' scores before and after the treatment. Furthermore, the very large effect size demonstrates that differentiated instruction has substantial educational value in improving students' mathematical conceptual understanding.

Conceptually, the improvement in students' understanding of quadratic function concepts can be analyzed through the constructivist perspective, which views knowledge as actively constructed by learners through learning experiences and cognitive interactions rather than directly transferred from teacher to students (Zwingmann et al., 2012). In mathematics learning, conceptual understanding cannot be developed merely through memorization of procedures but requires

students to actively construct relationships among mathematical concepts. Differentiated instruction provides opportunities for students to learn according to their readiness levels and learning characteristics, allowing the process of conceptual construction to occur more optimally.

In the context of quadratic function material, students are not only required to understand algebraic procedures but also to comprehend the relationships among mathematical representations, such as equations, coefficients, vertex points, and graph characteristics. According to the theory of mathematical representation, conceptual understanding develops effectively when students are able to connect and transition flexibly between various forms of mathematical representation (Skemp, 1976). Through differentiated instruction, students receive more adaptive learning experiences. For example, visual learners are supported through graph visualization activities, while students with higher readiness levels are encouraged to engage in exploratory and analytical tasks. Such learning conditions help students build relational understanding of quadratic function concepts more effectively.

The results of this study are also consistent with Skemp's theory of instrumental and relational understanding. Skemp distinguished mathematical understanding into instrumental understanding and relational understanding (Skemp, 1976). Instrumental understanding refers to the ability to apply formulas or procedures without understanding the underlying concepts, whereas relational understanding emphasizes understanding the relationships among mathematical concepts meaningfully. In conventional teacher-centered learning, students often focus only on procedural exercises, leading to instrumental understanding. In contrast, differentiated instruction enables students to develop relational understanding because the learning process is adjusted to students' learning needs and characteristics. This condition can be observed through students' improved ability to connect quadratic coefficients with the characteristics of the resulting graphs.

The improvement in students' conceptual understanding can also be explained through Vygotsky's Zone of Proximal Development (ZPD) theory. According to Vygotsky and Cole, students learn optimally when they receive appropriate assistance according to their cognitive development levels (Vygotsky & Cole, 1978). In differentiated instruction, the teacher adjusts learning activities based on students' readiness levels so that the support provided becomes more targeted. Students with lower initial abilities receive more structured guidance and scaffolding, while students with higher abilities are given more complex and challenging tasks. Such adjustments allow students to learn within their optimal developmental zone, thereby facilitating more effective conceptual understanding.

From the perspective of educational psychology, the findings of this study also indicate that differentiated instruction can increase students' cognitive engagement during mathematics learning. In self-determination theory, learning environments that provide students with a sense of competence and learning autonomy can enhance students' engagement in higher-order thinking processes (Deci & Ryan, 2000). This is particularly important in mathematics learning because conceptual

understanding requires students to analyze relationships, construct generalizations, and connect mathematical representations actively.

The findings of this study are in line with previous studies showing that differentiated instruction positively affects mathematics learning outcomes. Research conducted by Ayu & Pratiwi (2024) revealed that differentiated instruction effectively improved students' mathematical problem-solving abilities through learning adjustments based on students' needs. Similarly, Rohim et al. (2024) found that problem-based differentiated instruction positively influenced students' mathematical problem-solving skills because the learning process accommodated students' readiness levels. In addition, Nur & Rahmawati (2024) reported that differentiated instruction integrated with the Problem Based Learning model improved students' problem-solving abilities in relation and function material. Other studies also showed that differentiated instruction supported by GeoGebra and innovative learning models contributed positively to the development of students' mathematical abilities (Mulbar & Upu, 2025; Soliha, 2025).

The findings of this study are also consistent with several studies published in the Journal of Educational Sciences, which emphasized that differentiated learning can improve students' engagement, conceptual understanding, and learning achievement through adaptive and student-centered instructional strategies. Awofala & Lawani (2020) explained that differentiated instruction improved students' mathematics achievement by accommodating students' readiness and learning characteristics more effectively. Musfita et al. (2025) also reported that differentiated learning modules help improve students' understanding and learning outcomes through instructional activities adjusted to students' readiness, interests, and learning profiles. Similarly, Rosidah & Minsih (2026) found that differentiated learning creates more inclusive learning environments and enhances students' participation through flexible instructional approaches. Furthermore, Nofitasari & Nugraha (2025) reported that differentiated learning encourages active participation and increases students' motivation during classroom learning activities. Hariry et al. (2025) also revealed that differentiated learning supports more adaptive and student-centered classroom interactions because instructional activities are adjusted to students' learning needs and characteristics. These findings strengthen the argument that differentiated instruction provides meaningful learning experiences and supports students' conceptual understanding development.

The implementation of differentiated instruction in this study was also supported by several factors. Students showed active participation during learning activities because the learning process was adapted to their readiness levels and learning characteristics. The use of visual representations, collaborative discussions, and contextual exercises also helped students understand the abstract concepts of quadratic functions more easily. These conditions contributed positively to students' engagement and conceptual understanding during the learning process. However, several obstacles were also encountered during the implementation of differentiated instruction. Differences in students' academic abilities required the teacher to prepare varied learning activities and provide different levels of guidance

for each group of students. In addition, limited instructional time became a challenge in managing classroom activities and ensuring that all students received appropriate learning support. To address these challenges, the teacher implemented gradual guidance, grouped students according to their learning readiness, and optimized collaborative learning activities so that the learning process could remain effective and well-organized.

The practical implications of this study indicate that differentiated instruction can serve as an effective mathematics learning strategy, particularly for quadratic function material that requires strong conceptual understanding and representational abilities. Through differentiated instruction, teachers can accommodate the diversity of students' learning characteristics and create a more inclusive and meaningful learning environment. Therefore, differentiated instruction has the potential to improve not only students' learning outcomes but also the quality of mathematics learning processes in schools.

Nevertheless, the findings of this study should be interpreted carefully because the research employed a One-Group Pretest-Posttest Design without a control group. From the perspective of experimental methodology, this design still has limitations in internal validity because the improvement in learning outcomes cannot be fully attributed solely to differentiated instruction. Other factors, such as prior learning experiences, practice intensity, and students' learning motivation, may also have influenced the results. Therefore, future studies are recommended to employ stronger experimental designs involving control groups in order to examine the effectiveness of differentiated instruction more comprehensively.

Overall, the findings of this study demonstrate that differentiated instruction has strong potential to improve students' understanding of quadratic function concepts. This approach is not only pedagogically relevant in accommodating students' diverse learning characteristics but also aligned with the constructivist learning paradigm that positions students as active participants in constructing their mathematical understanding.

4. Conclusion

Based on the results of the study, it can be concluded that differentiated instruction has an effect on students' understanding of quadratic function concepts in class X of MAN 2 Palu City. The implementation of differentiated instruction helped students understand quadratic function concepts more effectively through learning processes adjusted to students' readiness levels, interests, and learning profiles. As a result, students obtained more adaptive, active, and meaningful learning experiences in understanding mathematical concepts.

The findings of this study imply that differentiated instruction can serve as an alternative mathematics learning approach that is relevant to be implemented in Madrasah Aliyah, particularly in improving students' mathematical conceptual understanding. This approach provides opportunities for teachers to accommodate

students' diverse learning characteristics so that the learning process does not occur uniformly but is more oriented toward students' learning needs. In addition, differentiated instruction also has the potential to create a more inclusive learning environment and encourage students' active participation in the mathematics learning process.

Nevertheless, this study still has several limitations because it employed a one-group research design without a comparison group, so the effect of the treatment could not be compared more objectively with other learning approaches. In addition, the study was conducted only on quadratic function material and involved a limited number of research subjects. Therefore, future studies are recommended to use stronger experimental designs involving control groups, broader material coverage, and more diverse research subjects so that the effectiveness of differentiated instruction can be examined more comprehensively.

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