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The effectiveness of differentiated learning strategies on student's concept understanding in matrix mathematics

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Abstract
Many students have difficulty understanding mathematical concepts because learning is still quite teacher-centred and does not pay attention to individual learning needs. Differentiated learning is seen as being able to overcome this problem by adjusting content and processes according to students' abilities and learning styles. This study aims to determine the effectiveness of differentiated learning in improving the mathematical concept understanding abilities of grade XI students at SMK Al Khozini Gondanglegi in the subject of matrices. This study used a quantitative method with a quasi-experimental design of the pretest and posttest control group type. The sample consisted of two classes, namely the experimental class with differentiated learning and the control class with conventional learning. Data were obtained from concept comprehension tests and analyzed using statistical tests. The results showed a significant increase in the experimental class with an average post-test score of 82.69 and an N-Gain of 0.57, which was higher than the control class with a post-test score of 68.42 and an N-Gain of 0.51. The t-test also showed a significant difference between the two classes (sig. 0.000 < 0.05). Thus, differentiated learning proved to be more effective than conventional learning in improving students' mathematical concept understanding of matrix material.
Keywords: differentiated learning; mathematical concept understanding; matrix; quasi-experimental; learning outcomes

Abstrak
Banyak peserta didik mengalami kesulitan memahami konsep matematika karena pembelajaran yang masih berpusat pada guru dan kurang memperhatikan kebutuhan belajar individu. Pembelajaran berdiferensiasi dipandang mampu mengatasi masalah tersebut melalui penyesuaian konten dan proses sesuai kemampuan dan gaya belajar siswa. Penelitian ini bertujuan mengetahui efektivitas pembelajaran berdiferensiasi dalam meningkatkan kemampuan pemahaman konsep matematis siswa kelas XI SMK Al Khozini Gondanglegi pada materi matriks. Penelitian menggunakan metode kuantitatif dengan desain Quasi Experimental tipe Pretest and Posttest Control Group. Sampel terdiri dari dua kelas, yaitu kelas eksperimen dengan pembelajaran berdiferensiasi dan kelas kontrol dengan pembelajaran konvensional. Data diperoleh dari tes pemahaman konsep dan dianalisis menggunakan uji statistik. Hasil penelitian menunjukkan peningkatan signifikan pada kelas eksperimen dengan nilai postes rata-rata 82,69 dan N-Gain 0,57 yang lebih tinggi dibanding kelas kontrol dengan nilai postes 68,42 dan N-Gain 0,51. Uji t juga menunjukkan perbedaan yang signifikan antara kedua kelas (sig. 0,000 < 0,05). Dengan demikian, pembelajaran berdiferensiasi terbukti lebih efektif dibandingkan pembelajaran konvensional dalam meningkatkan pemahaman konsep matematis peserta didik pada materi matriks.
Kata Kunci: pembelajaran berdiferensiasi; pemahaman konsep matematis; matriks; quasi experimental; hasil belajar

1. INTRODUCTION

Mathematics is a subject studied from elementary school to university. This subject aims to enable students to understand mathematical concepts, explain the relationships between concepts, and apply these concepts appropriately and efficiently to solve problems (Irshad, 2024; Serin, 2023; Torres-Peña et al., 2025). Based on this opinion, one of the skills students must master in mathematics learning is understanding mathematical concepts when solving problems (Samosir et al., 2023; Taskiya, 2023). Therefore, the achievement of mathematics learning can be determined by students' ability to understand and master the concepts presented (Hussein & Csíkos, 2023; Ncube & Luneta, 2025).

Students are said to have a good understanding of mathematical concepts if they are able to connect new knowledge with previously acquired knowledge, making it easier to solve math problems (Putri & Wutsqa, 2019). Conversely, if this is not the case, then understanding mathematical concepts will significantly impact the problem-solving process. The facts described above indicate that many students still lack a grasp of mathematical concepts (Kurudirek et al., 2025; Samosir et al., 2023). This can impact subsequent, more complex mathematics learning. Many students report that learning mathematics is difficult, intimidating, and unpleasant due to their low conceptual understanding (Muslimah & Witanto, 2025; Namkung et al., 2019; Van Der Beek et al., 2017).

In the context of classroom learning, problems related to students' understanding of mathematical concepts are still frequently found. Based on preliminary observations conducted at SMK Al Khozini Gondanglegi, several students experienced difficulties in understanding matrix concepts, especially in identifying matrix elements, performing matrix operations, and applying these concepts to solve contextual problems. This condition was reflected in the results of the initial test conducted by the researcher, which showed that many students obtained scores below the minimum mastery criteria. In addition, classroom observations indicated that learning activities were still dominated by teacher explanations, while students tended to be passive and relied heavily on procedural steps without fully understanding the underlying concepts. This situation shows that students' conceptual understanding in mathematics still needs to be improved through learning strategies that can accommodate differences in students' abilities and learning needs.

Researchers will implement a differentiated learning approach according to students' learning styles. (Ariesta, 2025) states that this strategy includes research into content differentiation and process differentiation. This strategy aims to ensure that each student has good learning skills. Differentiated learning is a meaningful pedagogical method developed by an educator who always pays attention to the needs of each individual student (Goyibova et al., 2025). In classroom learning, teachers provide material. This includes how to convey content, develop ideas, process ideas, and/or processes, to ensure each student has optimal learning abilities related to understanding mathematical concepts (Setambah et al., 2024). A differentiated learning approach must be able to address these challenges. This approach provides teachers with the freedom to adapt content and processes, ensuring that learning aligns with students' readiness, interests, and learning profiles (Aguhayon et al., 2023).

Based on previous research, the implementation of differentiated learning can improve understanding of mathematical concepts (Rijal et al., 2025). Several studies also state that with a differentiated learning approach, teachers can adjust. In this study, using content and process differentiation based on students' ability levels towards conceptual understanding. Therefore, this study is expected to determine the effectiveness of differentiated learning on aspects of mathematical concept understanding abilities, as well as provide theoretical and practical contributions. This indicates that the implementation of differentiated learning has not yet been fully implemented, even though the differentiated learning approach encourages students to actively explore ideas, develop problem-solving strategies, and reflect on their thinking processes. Furthermore, studies have shown that differentiated learning based on student needs significantly improves learning independence, self-confidence, and mathematics learning outcomes (Nurlaela et al., 2024; Slk & Fitriani, 2024).

Therefore, this study focuses on implementing differentiated learning by integrating content and process differentiation based on students' learning styles and ability levels to enhance students' understanding of mathematical concepts. This study not only examines the effectiveness of differentiated learning in mathematics classrooms but also explores how the adjustment of learning content and learning processes can accommodate diverse student characteristics in a more systematic way. In addition, this research provides a more comprehensive perspective by linking differentiated instructional strategies to students' conceptual understanding in mathematics, an area that has not been widely explored in previous studies. Through this approach, the study attempts to provide deeper insights into how differentiated learning can support students with different learning needs while simultaneously strengthening their conceptual mastery in mathematics.

This research is important to examine the effectiveness of the differentiated learning approach in improving students' understanding of mathematical concepts. Based on the problems and research gaps identified, this study focuses on grade XI students of SMK Al Khozini Gondanglegi. The objective of this research is to determine students' ability to understand mathematical concepts after the implementation of differentiated learning. Furthermore, this study evaluates the effectiveness of differentiated learning in supporting students' conceptual understanding of mathematics, particularly on matrix material.

2. RESEARCH METHOD

This study used an experimental class and a control class. A differentiated learning approach was applied to the experimental class, while the control class used conventional learning. To ensure student's concept understanding, both groups were given pretests and posttests throughout the study. The design used in the Quasi-Experimental Design is a Pretest and Posttest Control Group Design, where the experimental and control groups were not selected randomly. Quasi-experimental research involves numerical data to be analyzed using statistical tests (Campbell & Stanley, 1963). Two groups are compared: one experimental group receives a treatment and the other a control group receives no treatment. This method provides deeper insight into the effectiveness of the treatment. The scheme of the Pretest and Posttest Control Group Design in this study can be seen in Table 1 below.

Table 1. Pretest and Posttest Control Group Design Scheme

Class	Pretest	Treatment	Posts
Experimental Class	O_1	X	O_2
Control Class	O_3	-	O_4

Information:

O_1: *pretest* experimental class before being given treatment

O_3: *pretest* control class before being given treatment

O_2: *posts* experimental class after being given treatment

O_4: post-test of the control class after being given treatment

X: Treatment using differentiated learning

- : Treatment using conventional learning

This study began by assessing the initial abilities of students in both classes by administering a pretest before administering the treatment. The first class, the experimental class, was given treatment using a differentiated learning approach, while the second class, the control class, was given treatment using conventional learning. The same posttest was then administered. Next, the post-test results from the experimental class were then compared with the post-test results from the control class.

Research Population states that a population is all objects, individuals, or entities that are the target or scope of a study. A population includes all elements that have certain characteristics relevant to the research objectives. The population in this study was all grade XI AD students at SMK Al Khozini Gondanglegi for the 2025/2026 academic year, which were divided into four classes.

Table 2. Research Population

No.	Class	Number of Students
1	XI-A	32
2	XI-B	32
3	XI-C	28
4	XI-C	26
	Amount	118

Research Sample is a sample is a subset of the population and its characteristics. Samples must be truly representative so that research results can be generalized. The research design used is Quasi Experimental Design, so the sampling method is carried out by non-probability sampling or non-random sampling. The sampling technique used in this study is purposive sampling, the selection of samples is adjusted to the objectives and research questions being studied. In this study, two classes were selected from four parallel classes at SMK Al Khozini Gondanglegi for the 2025/2026 Academic Year based on the consideration and supervision of the mathematics subject teacher as the basis for class selection. The experimental class is class XI-A, which consists of 32 students and is given treatment in the form of differentiated learning. The control class is class XI-B, which also consists of 32 students and is taught using conventional learning methods.

Both classes were given a pretest before the treatment and a posttest after the learning process was completed. Comparing the learning outcomes of the two groups served as the basis for assessing the effectiveness of the treatment. This study involves two variables, there are independent variable: differentiated learning and dependent variable: students' ability to understand mathematical concepts. The instrument was a descriptive test containing eight questions to measure understanding of mathematical concepts. The test was administered during the pretest and posttest, using the same indicators. Instruments are tested for suitability before use validity was tested using product-moment correlation. All test items were declared valid and reliability was tested using Cronbach's Alpha. The pretest reliability value was 0.825 and the posttest reliability value was 0.798, both of which are considered high, thus declaring the instrument reliable.

Data collection was carried out in two stages: Pretest to determine the initial abilities of students in both classes, Posttest to determine the increase in abilities after treatment, changes in learning outcomes were analyzed based on the difference in scores of the two tests. Data analysis was carried out in two stages: Descriptive Statistics, used to describe student learning outcomes through average values, standard deviations, highest and lowest values. Inferential Statistics include: 1) Normality Test: using Shapiro-Wilk to ensure the data is normally distributed. 2) Homogeneity Test: to ensure that the variances of the two groups are the same. 3) T-test: used to determine the differences in learning outcomes between the experimental class and the control class in the pretest and posttest scores. 4) N-Gain Test:to determine the level of improvement in conceptual understanding after treatment. All statistical tests were carried out using SPSS software, the following table shows the differences between the experimental class and the control class.

Table 3. Components of the Experimental Class and Control Class

Component	Experimental Class	Control Class
Learning model	Differentiate according to readiness, interests, and learning profiles	Conventional teacher-centered
Pretest	Measuring initial conceptual understanding abilities	Measuring initial abilities conceptual understanding
Treatment	Providing materials through content and assignment adjustments	One-way and uniform delivery of material
Posttest	Measuring learning outcomes after Treatment	Measuring learning outcomes after Treatment
*Output*Analysis	Mean, Standard Deviation, N-Gain Test, and t-Test	Mean, Standard Deviation, N-Gain Test, and t-Test

The results of the pretest and posttest instrument tests can be seen from the following validity and reliability aspects.

Table 4. Instrument Test Results

Aspect	*Pretest*	*Posttest*	Information
Validity	All items are valid (r count 0.433–0.792 > r table 0.349)	Valid (r count 0.401–0.775 > r table)	Worth using
Reliability (Cronbach's Alpha)	0.825	0.798	High reliability
Difficulty Level	Moderate–difficult	Moderate–easy	Worth using
Distinguishing Power	Pretty good	Pretty good	High reliability

3. RESULT AND DISCUSSION

This study was conducted on eleventh-grade students at SMK Al Khozini Gondanglegi to measure the effectiveness of differentiated learning on mathematical concept understanding. The study involved an experimental class and a control class, using valid and reliable test instruments. The experimental class was class XI-A with 32 students who participated in differentiated learning on matrix material for five meetings. The approach used included differentiating content and processes based on students' level of understanding and learning styles. Prior to the learning, a pretest was conducted to assess initial abilities. Students were then grouped into three understanding categories (high, medium, and low) as a basis for developing content and implementing differentiated learning.

The control class was class XI-B, which received conventional mathematics instruction. The study in this class was conducted over four meetings as a comparison to the experimental class.

Table 5. Comparison of Pretest Results of Experimental Class and Control Class

No	Information	Pretest	
		Experiment	Control
1	The highest score	72	62
2	Lowest Value	41	39
3	Number of Students	32	32
4	Average	56.68	51.65

Pretest data was collected before the learning treatment. The experimental class used differentiated learning, while the control class used conventional methods. The results showed that the experimental class had a highest score of 72, a lowest score of 41, and an average score of 56.68. Meanwhile, the control class had a highest score of 62, a lowest score of 39, and an average score of 51.65. This indicates that the initial abilities of the two classes were relatively small before the treatment was administered. To find out the comparison of the post-test scores of the experimental class and the control class, you can seen from the following table.

Table 6. Comparison of Post-test Results of Experimental Class and Control Class

No.	Information	Posts	
		Experiment	Control
1	The highest score	95	78
2	Lowest Value	63	56
3	Number of Students	32	32
4	Average	82.69	68.42

Posttest data were collected after the treatment was administered. The results showed that the experimental class achieved a higher average score of 82.69 compared to the control class's 68.42. The highest score for the experimental class was 95 and the lowest was 63, while the highest for the control class was 78 and the lowest was 56. This difference indicates that differentiated learning is more effective in improving students' understanding of mathematical concepts. Next, statistical data on the N-Gain score obtained related to the ability to understand mathematical concepts in the experimental class are presented in the following table.

Table 7. Statistical Data of N-Gain Values of Experimental Class

N-Gain Score Data for Mathematical Concept Understanding Ability	
Number of Students	32
Highest Score	0.90
Lowest Score	0.172
Average	0.57

The experimental class' N-Gain value showed a higher increase, with the highest score being 0.90, the lowest being 0.172, and an average of 0.57. These results indicate that differentiated learning provides a better understanding of mathematical concepts for students. Furthermore, statistical data on N-Gain scores related to students' mathematical concept understanding abilities are presented in the following table.

Table 8. Statistical Data of N-Gain Values of Control Class

N-Gain Score Data for Mathematical Concept Understanding Ability	
Number of Students	32
Highest Score	0.759
Lowest Score	0.251
Average	0,51

The N-Gain results for the control class showed an increase in mathematical concept understanding, with the highest score being 0.759, the lowest being 0.251, and an average of 0.51. Although lower than the experimental class, these data still indicate an improvement through conventional learning.

3.1. Normality Test

The normality test is a procedure used to determine whether the data is normally distributed or not. The normality test in this study uses the formula *Shapiro-Wilk*.The number of samples in each class was 32 students.

Table 9. Normality Test Results

Tests of Normality							
		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Class	Statistic	Df	Sig.	Statistic	df	Sig.
Results	Pretest_A(Experiment)	.134	32	.151	.973	32	.593
	Posttest_A(Experiment)	.160	32	.136	.953	32	.170
	Pretest_B(Control)	.116	32	.200*	.960	32	.268
	Posttest_B(Control)	.103	32	.200*	.974	32	.607
*. This is a lower bound of the true significance.							
a. Lilliefors Significance Correction							

Based on Table 9, the results of the normality test using Shapiro-Wilk show that the significance value of the N-Gain score of the experimental class is 0.170, while the control class is 0.200. Because the significance values of both classes are greater than the alpha value (0.05), namely 0.170 > 0.05 and 0.200 > 0.05, then H0 is accepted and H1 is rejected. This means that the N-Gain score data in the experimental class and the control class are normally distributed.

3.2. Homogeneity Test

After the normality test is performed, the next step is the homogeneity test. The homogeneity test aims to determine whether data from several classes have the same or different variances. If the data variances are homogeneous (equal), then parametric statistical analysis can proceed with that assumption. The results of the homogeneity test in the study are as follows.

Table 10. Homogeneity Test Results

Test of Homogeneity of Variance					
		Levene Statistics	df1	df2	Sig.
Learning outcomes	Based on Mean	1,330	1	62	.253
	Based on Median	.696	1	62	.407
	Based on Median and with adjusted df	.696	1	51,714	.408
	Based on trimmed mean	1,223	1	62	.273

Based on the results of the homogeneity of variance test shown in Table 10, the significance value obtained in the Based on Mean calculation was 0.253 (> 0.05). Thus, it can be concluded that the N-Gain variance in the experimental and control classes is the same (homogeneous). The results of the independent sample t-test using SPSS version 26 are as follows.

Table 11. Group Statistics

	Class	N	Mean	Std. Deviation	Std. Error Mean
Mark	Posttest_Experiment	32	82.69	7.041	1.245
	Ponttest_Kontrol	32	68.53	5.400	.955

An independent sample t-test was used to determine the difference in means between two unpaired classes. Based on the calculation, the experimental class had a post-test mean of 82.69 and the control class 68.53. Descriptively, the difference in ability is quite clear, so a t-test is necessary to determine whether the difference is statistically significant. It is necessary to see the results of the t-test in the next table.

Table 12. Independent Samples Test

		Independent Samples Test							
		Levene's Test for Equality of Variances		t-test for Equality of Means					
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Standard Error Difference	95% Confidence Interval of the Difference Lower Upper
Mark	Equal variances assumed	1,330	.253	9,025	62	.000	14,156	1,569	11,021 17,292
	Equal variances not assumed			9,025	58,094	.000	14,156	1,569	11,016 17,296

The results of the independent sample t-test showed a significance value of 0.000 < 0.05, which means there is a significant difference in the average between the experimental class and the control class. This difference confirms that differentiated learning has a positive influence on improving the understanding of mathematical concepts of grade XI students of SMK Al Khozini Gondanglegi.

The analysis results showed a clear improvement in mathematical concept comprehension after the implementation of differentiated learning. The average score of the experimental class increased from 56.68 in the pretest to 82.69 in the posttest. The highest score increased from 72 to 95, and the lowest score from 41 to 63. Improvements occurred in almost all students, both low- and high-ability students, demonstrating that this approach is capable of accommodating individual differences.

The experimental class' average N-Gain was 0.57, falling within the moderate to high category. This indicates that content and process differentiation effectively enhances mathematical concept understanding. These results align with expert opinion that differentiated learning helps students understand material according to their readiness and learning style. In contrast, the average N-Gain for the control class was only 0.51, although it still experienced an increase, but not as significant as the experimental class. This indicates that conventional learning does not provide optimal space for each student's development.

These findings are consistent with previous research demonstrating that differentiated instruction enhances student engagement, fosters learning autonomy, and facilitates deeper cognitive processing of content (Ramaila, 2025). The notable improvement among both higher- and lower-performing students in the experimental class underscores the approach's capacity to provide equitable learning opportunities (Valiandes, 2015). For students who initially experienced difficulty, differentiation supplies targeted scaffolding and alternative learning routes that support the acquisition of key concepts. Meanwhile, advanced learners benefit from enriched tasks and flexible pacing, which sustain their academic growth and prevent stagnation.

This effectiveness can be explained from the perspective of how differentiated instruction supports conceptual learning in mathematics. Mathematical concept understanding requires students to actively construct knowledge, connect prior knowledge with new information, and apply concepts in various contexts(Rani et al., 2025). Differentiated learning facilitates this process by providing learning experiences that match students' readiness levels and cognitive needs (Lopis et al., 2025). Through content and process differentiation, students are given opportunities to explore mathematical ideas using different representations, problem-solving approaches, and learning activities. Such learning conditions enable students to engage more deeply with mathematical concepts, rather than merely memorizing procedures. Consequently, differentiated instruction can strengthen students' conceptual understanding because it creates a learning environment that supports active thinking, meaningful learning, and conceptual connections in mathematics.

The statistically significant differences between the experimental and control groups further strengthen these theoretical perspectives. However, beyond the numerical evidence, the results highlight the need for educators to critically examine and refine their instructional practices. The moderate-to-high N-Gain achieved by the experimental class demonstrates that substantial learning progress stems not solely from increased instructional time, but from the deliberate quality and adaptability of the instructional design. In contrast, the lower N-Gain of the control class—though indicative of some level of learning—reveals the constraints of relying on uniform teaching methods in classrooms characterized by learner diversity.

Taken together, these insights hold important implications for mathematics instruction in secondary vocational education. Vocational students often present diverse academic backgrounds and varying degrees of mathematical readiness. Differentiated instruction offers a pedagogical framework capable of addressing these complexities by cultivating learning environments that are more inclusive, responsive, and equitable (Koimah et al., 2024). While adopting such approaches may require shifts in teacher mindset, classroom management, and instructional planning, the demonstrated advantages provide a compelling rationale for these pedagogical innovations (Sinambela & Sinaga, 2024).

Overall, differentiated learning has been shown to be more effective than conventional learning methods in improving students' understanding of mathematical concept (Rijal et al., 2025). Through this approach, teachers can adjust learning activities based on students' readiness, interests, and learning profiles so that each student receives learning experiences that suit their needs (Shemshack et al., 2021). This flexibility allows students who experience difficulties to receive more guidance, while students with higher abilities can be given more challenging tasks. As a result, students have greater opportunities to develop a deeper understanding of mathematical concepts and apply these concepts when solving problems (Kholid et al., 2021). In addition, learning that accommodates differences in student abilities can create a more inclusive learning environment and support more equitable learning outcomes. This indicates that differentiated learning strategies can contribute positively to improving students' academic achievement in mathematics.

4. CONCLUSION

Based on the data analysis, there was a significant difference between the experimental class using differentiated learning and the control class using conventional learning. The experimental class experienced a greater increase in mathematical concept understanding than the control class. The pretest and posttest results in the experimental class showed a significant improvement, reinforced by the t-test results which showed a significance value of 0.000 < 0.05. The average N-Gain value of the experimental class was 0.57, higher than the control class of 0.51. Thus, differentiated learning was proven to be effective and had a positive effect in improving the understanding of mathematical concepts of grade XI students of SMK Al Khozini Gondanglegi.

Based on these findings, it is recommended that teachers consider implementing differentiated learning strategies to support students' conceptual understanding in mathematics learning. For future research, it is suggested to explore the implementation of differentiated learning in different mathematical topics, educational levels, or with larger samples in order to obtain more comprehensive results. In addition, further studies can examine other variables such as students' learning motivation, problem-solving skills, or critical thinking skills to enrich the understanding of the effectiveness of differentiated learning in mathematics education.

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