Differentiated learning with problem-based learning model in enhancing mathematical reasoning ability viewed from learning styles

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Abstract
This study examines the differences in students' mathematical reasoning abilities regarding triangles and special lines before and after implementing differentiated learning strategies using the Problem-Based Learning (PBL) model. It also explores how students' visual, auditory, and kinesthetic learning styles affect their mathematical reasoning outcomes. Conducted in a private junior high school in Sukabumi Regency, the quantitative experimental study involved 32 eighth-grade students. Participants were categorized based on their learning styles and class performance. Data collection included mathematics tests and interviews, analyzed through triangulation. Prior to treatment, 56% of students were identified as visual learners, while 22% were auditory and 22% kinesthetic. Following the pre-test on mathematical reasoning and PBL treatment, post-test results showed a significant improvement in students' abilities. The auditory learning style group achieved the highest average post-test score of 65.071. Contributing factors included: 1) greater engagement in discussions among auditory learners, who are naturally inclined to communicate, allowing for immediate resolution of misunderstandings; 2) more robust discussion activities within the auditory group; 3) auditory students' strengths in verbal tasks and receptive skills for verbal instructions; and 4) their ability to effectively convey information through oral and written communication, enhancing the quality of discussions. Overall, the findings suggest that differentiated learning through the PBL model positively impacts mathematical reasoning, particularly for auditory learners.

Keywords:
Differentiated learning strategies;
Problem-Based Learning (PBL);
Mathematical reasoning ability;
Visual learning style;
Auditory learning style;
Kinesthetic learning style

1. Introduction

Mathematics is a science that requires high comprehension skills in the learning process, enabling individuals to represent mathematics in a more easily digestible form and connect existing facts. Roziq (2019) reinforces this fact by stating that mathematics requires concrete evidence for easy understanding. The process of constructing concrete evidence involves combining fragmented elements into a more concrete understanding. This explanation aligns with Cindyana's (2022) explanation of reasoning ability, which describes it as a thought process for finding relationships between facts and drawing conclusions, making it crucial in learning mathematics.

Reasoning is also discussed in mathematics learning under the term "mathematical reasoning ability." Shadiq (2014) argues that mathematical reasoning is a process or thinking activity to draw conclusions, and make true statements based on certain proven statements. This mathematical reasoning ability is essential to develop. Sokolowski (2018) states that mathematical reasoning ability is vital because it is related to imagination and the ability to construct, retrieve, and explore internal representations that form the basis of learning mathematics. The indicators of mathematical reasoning that will be investigated in this study are based on Mullis, et al. (2009), which include analytical, generalization, synthesis, justification, and non-routine problem-solving abilities. These abilities encompass processing and understanding information, making statements with universal applicability, connecting concepts or elements as needed, proving obtained solutions, and solving problems in various contexts in everyday life.

Although teachers acknowledge the importance of mathematical reasoning, many students in Indonesia struggle with learning mathematics. This is due to several factors, such as difficulty understanding abstract mathematical concepts (Damayanti, 2019), rigid learning approaches with a lack of real-world connections, and limited opportunities for students to discover solutions independently (Dahlan, 2018). Consequently, Indonesian students' mathematical reasoning abilities remain low, as evident in PISA results. In 2015, Indonesia ranked 63rd out of 70 countries, followed by 73rd out of 79 countries in 2018, and 68th out of 81 countries in 2022. This low ability stems from students' difficulty in understanding mathematical abstraction and a lack of higher-order thinking cognitive abilities.

Field research by Pradestya, et al. (2024) on 12 eighth-grade students in Sukabumi Regency showed that no student achieved 50% of the maximum score in the mathematical reasoning test, indicating low mathematical reasoning abilities. Interviews with students revealed difficulties in understanding the meaning of questions, analyzing new situations, and generalizing concepts. Students also admitted their reliance on conventional learning and a lack of ability to explore information independently. Despite the implementation of various learning models such as Problem-Based Learning and PMRI (Marfu'ah, et al., 2022), mathematical reasoning abilities remain low. Aprilianti, et al. (2019) identified several contributing factors, including difficulty remembering material, a lack of ideas in solving problems, and a lack of understanding of concepts and formulas. A more comprehensive approach is needed to address this issue.

While various studies have been conducted to address the aforementioned factors, particularly since the implementation of the Merdeka Curriculum, further research is needed to ensure the effectiveness of differentiated learning approaches in enhancing students' mathematical reasoning abilities across Indonesia. The Merdeka Curriculum encourages the use of learning models tailored to students' learning characteristics, and research by Nur'azizzah, et al. (2023) shows an improvement in mathematical reasoning abilities after implementing differentiated learning that considers students' learning styles. However, further research is necessary to ensure that these findings can be generalized to all regions of Indonesia. Therefore, based on the above explanations, the researcher is optimistic that differentiated learning strategies with a Problem-Based Learning model approach can be a solution to the aforementioned problems.

Duch (in Lestari & Yudhanegara, 2015) suggests that PBL is a learning model that challenges students to learn how to learn, work in groups to find solutions to real-world problems. Arends (in Lestari & Yudhanegara, 2015) explains that PBL is a learning model where students are presented with authentic (real) problems, enabling them to construct their own knowledge, develop inquiry and higher-order skills, become independent learners, and boost their confidence. PBL can be a solution to the problem of low mathematical reasoning abilities because it requires students to solve problems in their own way. The approach used by each student will inevitably differ based on their individual learning characteristics, or in other words, their learning styles.

Every student has a different learning style, known as learning modality (Yuwanita, et al., 2020). Learning that aligns with students' learning styles will be easier to understand (Supit, et al., 2023). There are three types of learning styles: auditory (listening), kinesthetic (moving), and visual (seeing). Due to differences in student characteristics, education must be tailored to their preferences. If students experience difficulties in mathematical reasoning, it is crucial to identify and understand the factors contributing to these difficulties, including their learning styles.

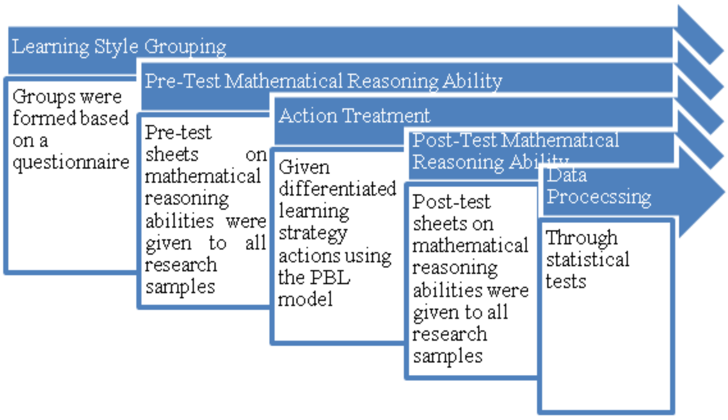
Based on the above explanations, the researcher believes that a solution to this situation must be found promptly. Therefore, this research aims to investigate further the implementation of differentiated learning strategies with the PBL model on improving the mathematical reasoning abilities of each student based on their learning styles. This is essential to determine if this learning approach can enhance students' mathematical reasoning abilities based on their individual learning styles, considering that mathematical reasoning ability is crucial and needs to be developed to improve the quality of mathematics education in Indonesia.

2. Method

Research methods refer to specific types of research designs that employ particular procedures. This study utilizes a quantitative research approach. The research was conducted at a private junior high school in Sukabumi Regency, West Java, involving 32 samples from the eighth grade with diverse learning styles. The quantitative research was conducted with data testing from one experimental class using a one-group pre-test and post-test design to examine whether students' mathematical reasoning abilities improved compared to before the implementation of differentiated learning strategies with the PBL model.

The research instruments included a learning style questionnaire, pre-test, and post-test sheets for mathematical reasoning, which were validated by experts and tested for validity and reliability. The questionnaire scores were used to classify students' learning styles, with a tendency towards one learning style indicated by the highest score for each student. The pre-test and post-test scores were used to test the hypothesis through appropriate statistical tests.

Figure 1
Data Analysis Flow

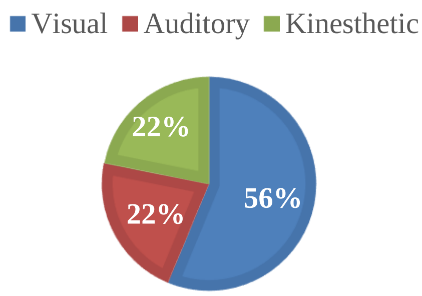


3. Results and Discussion

3.1 Results

The initial data was obtained from the learning style questionnaire scores. The learning style questionnaire was administered to 32 students using a questionnaire sheet during the learning process. The learning style with the highest score on the questionnaire indicates each student's learning style. Here is the data on learning styles obtained.

Figure 2
Student Learning Style Classification Chart



The analysis of the learning style questionnaire data revealed that the class is dominated by students with a visual learning style, indicating that most students in this class absorb information more easily through sight. The other learning styles are distributed evenly, each representing 22%. After the learning style classification was established, all students were given a pre-test of mathematical reasoning ability as baseline data. Subsequently, a differentiated learning strategy with the PBL model was implemented on the material of triangles and special lines in triangles until the final stage, which was the post-test. Here are the scores obtained by each sample.

Table 1
Obtaining Mathematical Reasoning Ability Test Scores

Sample	Learning Style	Pre-Test	Post-Test
Sample 1	Visual	33	82,75
Sample 2	Visual	15	37,5
Sample 3	Visual	32	63,25
Sample 4	Auditory	15	43,75
Sample 5	Auditory	24	24,25
Sample 6	Kinesthetic	23	37,75
Sample 7	Visual	19	60,75
Sample 8	Auditory	22	75
Sample 9	Auditory	26	60
Sample 10	Visual	24	39,75
Sample 11	Visual	15	44,5
Sample 12	Visual	18	36
Sample 13	Visual	19	36
Sample 14	Visual	25	82,75
Sample 15	Visual	23	39,75
Sample 16	Auditory	26	75
Sample 17	Kinesthetic	32	80
Sample 18	Kinesthetic	23	62,75
Sample 19	Visual	37	88,75
Sample 20	Kinesthetic	14	17,5
Sample 21	Auditory	30	92,5
Sample 22	Auditory	20	85
Sample 23	Kinesthetic	22	37,75
Sample 24	Visual	28	82,75
Sample 25	Visual	12	49,5
Sample 26	Kinesthetic	24	37,75
Sample 27	Visual	27	82,75
Sample 28	Visual	0	17,5
Sample 29	Visual	25	82,75
Sample 30	Visual	28	81,25
Sample 31	Kinesthetic	22	62,75
Sample 32	Visual	19	36
Average		22,5625	57,375

Based on the data in Table 1, it appears that all samples experienced an increase in post-test scores for mathematical reasoning ability compared to their pre-test scores. It is also evident from the obtained values that the highest score was achieved by Sample 21, with an auditory learning style, with a score of 92.5. Based on the data in Table 1 above, the average post-test scores for each learning style are presented in Table 2 below.

Table 2
Average Post-Test Scores of Mathematical Reasoning Ability by Learning Style

Learning Style	**Average**
Visual	58,0138889
Auditory	65,0714286
Kinesthetic	48,0357143

Based on Table 2 above, it can be observed that the highest average post-test score is held by the auditory learning style group. This indicates that students with an auditory learning style in the implementation of differentiated learning with the PBL model performed better compared to other learning style groups. Although the topic discussed in this research is related to geometry, which should be an advantage for students with a visual learning style, the auditory group was able to outperform them.

Before conducting the alternative test, the data in Table 1 was first tested for normality, and the results are presented below.

Table 3
Data Normality Test

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	Df	Sig.	Statistic	Df	Sig.
Pre	.125	32	.200*	.957	32	.230
Post	.154	32	.051	.911	32	.012

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

In the table above, the decision was made by observing the Sig. value in the Shapiro-Wilk Table. This was done because the number of samples used was less than 50 (Sugiyono, 2014:114). Based on the Sig. value in the table, the pre-test value has a Sig. of 0.230 > 0.05. This indicates that H_0 is accepted, meaning that the pre-test data comes from a normally distributed population. On the other hand, the Sig. value for the post-test is 0.012 < 0.05. This indicates that H_0 is rejected, meaning that the post-test data comes from a population that is not normally distributed. Based on these test results, the assumptions for parametric testing are not met (coming from a normally distributed and homogeneous population). Therefore, it can be concluded that the hypothesis test to be used is a non-parametric test. The appropriate alternative test for the one-group pre-test and post-test design is the Wilcoxon Test. The results of the Wilcoxon test on the data in Table 4 are presented below.

Table 4
Wilcoxon Test Results

Test Statistics[a]	
	Post – Pre
Z	-4.937[b]
Asymp. Sig. (2-tailed)	.000

The Asymp. Sig (2-tailed) value is 0.000 < 0.05. Based on this value, it can be concluded that H_0 is rejected. This can be used as a basis for concluding that there is a significant difference between students' mathematical reasoning abilities before and after receiving differentiated learning strategies with the PBL model on the topic of triangles and special lines in triangles. The difference can be seen more clearly in Table 5 below.

Table 5
Description of the Difference in Pre-Test and Post-Test Scores for Mathematical Reasoning Ability

Ranks

		N	Mean Rank	Sum of Ranks
Post - Pre	Negative Ranks	0[a]	.00	.00
	Positive Ranks	32[b]	16.50	528.00
	Ties	0[c]		
	Total	32		

a. Post < Pre
b. Post > Pre
c. Post = Pre

Based on the table above, the Positive Ranks column has a value of 32 (equal to the total number of samples in the experimental class). This indicates that all students have higher post-test scores compared to their pre-test scores, with an average increase of 16.5 (as seen in the Mean Rank column). This reinforces the conclusion that there is a significant difference between students' mathematical reasoning abilities before and after receiving differentiated learning strategies with the PBL model on the topic of triangles and special lines in triangles. The difference is that students' mathematical reasoning abilities are better compared to before receiving differentiated learning strategies with the PBL model.

3.2 Discussion

The research findings indicate a significant difference in students' mathematical reasoning abilities before and after receiving differentiated learning strategies with the PBL model on the topic of triangles and special lines in triangles. The difference is that students' mathematical reasoning abilities are better compared to before receiving differentiated learning strategies with the PBL model. Differentiated learning provides freedom for all students to learn according to their preferences and interests. This aligns with Tomlinson (2001) and Sarie (2022), who state that differentiated learning provides opportunities for students to develop their potential based on their individual needs and characteristics. Research by Ardiawan, et al. (2024), supports this statement by demonstrating that differentiated learning strategies are proven effective in improving student learning outcomes. Furthermore, regarding PBL, Ernawati, et al. (2023) mention that PBL has a significant positive impact on learning. This approach helps students understand basic concepts better, fosters a positive attitude towards learning, and improves their overall performance. Based on these explanations, it can be said that differentiated learning strategies with the PBL model have a positive impact on students' mathematical reasoning abilities. This aligns with Cindyana, et al. (2022), and Nur'azizzah, et al. (2023), who state that differentiated learning strategies can enhance mathematical reasoning abilities. The results of this research are also in line with Rhofiqah & Thaariq (2019) and Hasibuan, et al. (2022), who state that PBL influences the improvement of students' mathematical reasoning abilities. The results of this research are consistent with similar previous studies. Through this research, it can be concluded that the use of differentiated learning strategies with the PBL model can have a positive impact on students' mathematical reasoning abilities. This result has answered the research questions in this study.

Based on Figure 2, the experimental class is dominated by students with a visual learning style, with 56% or 18 students out of 32. This indicates that the proportion of students with a visual learning style is more than half of the number of students in the experimental class. There are several factors contributing to this condition: a) Globalization in today's era, especially social media, more often displays visual images, transitions, and animations. Although accompanied by audio, the presentation of visual images, transitions, and animations is the main attraction in information delivery in this era. This factor has contributed to students becoming accustomed to visual activities, b) Information sources that include sketches are more appealing than information in the form of narrative paragraphs alone, so information can be conveyed more effectively to recipients, c) Learning methods through listening are usually conducted in lectures, which are conventional learning methods. Lectures are very tedious for students because they are not given opportunities to be creative (Wirabumi, 2020) and improvise their learning methods, and students are required to listen only. This makes visual learning more appealing than simply listening, d) Learning methods through practice are considered inefficient because in some cases they require high costs and take more time. This leads to this method being conducted only occasionally, so students are not accustomed to practical learning methods. This makes visual learning more practical and appealing compared to practical learning, and e) Habitual learning using visualization approaches makes students accustomed to visual things, fostering an interest in visual things. Ultimately, an interest in visualization leads students to have a visual learning style.

The topic studied by the students in this research is triangles and special lines in triangles. In mathematics, this topic falls under the sub-topic of geometry, which is a sub-topic that is favored by students with a visual learning style. However, based on Table 2, it is known that the auditory group obtained a higher average post-test score compared to other learning style groups. However, if you pay attention, the topic discussed in this research is geometry, which should be an advantage for visual learning styles that tend to excel in visual association (Al-Hamzah & Awalludin, 2021). The topic discussed in this research should also be an advantage for the kinesthetic group because this topic can be solved through experiments, direct measurements, or manipulation, which are strengths for students with a kinesthetic learning style (Al-Hamzah & Awalludin, 2021). However, in reality, the auditory group is superior. This result aligns with the findings of Wahyudi & Walid (2020), who state that the mathematical reasoning abilities of the auditory learning style group are better compared to other learning style groups. The contributing factors obtained from the results of this research are: a) The auditory group is more intense in discussions. This is because the characteristics of students in the auditory group are fond of talking and discussing (Al-Hamzah & Awalludin, 2021), so differences in understanding can be immediately resolved, b) Discussion activities are more established in the auditory group compared to other learning style groups, c) The advantage possessed by auditory students, namely excelling in verbal activities and being able to receive verbal instructions well (Purbaningrum, 2017). This advantage is a unique advantage for the auditory group so that the discussions conducted are meaningful and able to teach each other, d) The ability to convey information through oral and written communication well from students in the auditory group is an additional factor in carrying out discussions.

The above factors contribute to the higher average post-test scores of mathematical reasoning ability possessed by the auditory group compared to other groups. It is also proven that the highest score was obtained by Sample 21, a student with an auditory learning style, with a score of 92.5.

4. Conclusion

Based on the results and discussion above, it can be concluded that there is a difference between students' mathematical reasoning abilities before and after receiving differentiated learning strategies with the PBL model. Students' mathematical reasoning abilities are better compared to before receiving differentiated learning strategies with the PBL model. Differentiated learning provides freedom for all students to learn according to their preferences and interests. Meanwhile, PBL helps students understand basic concepts better, fosters a positive attitude towards learning, and improves their overall performance.

Based on the conclusion above, the implications of this research generally explain that the use of differentiated learning strategies with the PBL model can improve students' mathematical reasoning abilities. More specifically, the implications of this research are: 1) Differentiated learning strategies with the PBL model can be used as the main strategy in improving mathematical reasoning abilities. Based on the syntax used, students are more active in learning activities. Students actively acquire, process, learn, and construct new knowledge, and students are able to actively participate in problem-solving, 2) The use of differentiated learning strategies with the PBL model can accommodate students' learning characteristics based on their individual learning styles, so students learn well and effectively, 3) Differentiated learning strategies with the PBL model can be used as an alternative for any mathematics learning, whether geometry, numbers, algebra, measurement, or combinatorics, 4) Empirically and theoretically, the results of this research support previous research findings and theories, which reveal that differentiated learning strategies with the PBL model can improve students' mathematical abilities, especially students' mathematical reasoning abilities. The results of this research provide important guidance for future researchers, developers of learning strategies and models, teachers, and curriculum developers to implement differentiated learning strategies with the PBL model on other mathematical materials.

Here are some suggestions that can be implemented based on the results of the research that has been conducted: 1) The use of differentiated learning strategies with the PBL model should be implemented in other mathematics topics, 2) Further development of syntax is needed that can accommodate all differentiations (content, process, and product) to make learning more effective in addressing problems based on individual learning styles, 3) Differentiated learning strategies with the PBL model can be used in extracurricular and extracurricular activities to develop students' potential, 4) Differentiated learning strategies with the PBL model can be used by teachers to improve students' mathematical reasoning abilities, 5) Differentiated learning strategies with the PBL model can be used as input for education observers or policymakers to be used in making changes in mathematics learning that pay attention to the aspect of students' learning styles.

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