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Analysis of Conceptual Understanding in Matrix Operations among Grade XI Students of SMA Negeri 5 Palu Viewed from Learning Styles

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A B S T R A C T

Conceptual understanding is an essential ability in mathematics learning, particularly in the topic of matrix operations, which requires accuracy and interconnection among concepts. This study aims to describe students' mathematical conceptual understanding in solving matrix operations, viewed from visual, auditory, and kinesthetic learning styles. The research employed a descriptive qualitative approach with three Grade XI students, each representing one category of learning style. Data were collected through a conceptual understanding test on matrix operations and in-depth interviews, then analyzed through the stages of data condensation, data presentation, and conclusion drawing. The findings indicate that students with a visual learning style are able to understand concepts through table representations and the arrangement of matrix elements, yet still face difficulties in modeling word problems. Students with an auditory learning style can explain concepts orally in a structured manner, but show less consistency in calculation accuracy. Meanwhile, students with a kinesthetic learning style are able to grasp concepts through direct activities and modeling, and present solution steps systematically. The conclusion of this study highlights that differences in learning styles influence the characteristics of students' mathematical conceptual understanding in solving matrix operations.

1. Introduction

Mathematical conceptual understanding is one of the main objectives in mathematics learning and serves as a crucial foundation for students' success in studying mathematical topics at subsequent levels of education. Conceptual understanding is not merely defined as the ability to memorize formulas or follow problem-solving procedures, but encompasses students' ability to restate concepts in their own words, classify objects based on specific properties, provide examples

and non-examples, use procedures appropriately, and apply concepts in various problem-solving situations (Kesumawati, 2008; Mawaddah & Maryanti, 2016). Students with strong conceptual understanding are not only able to solve routine problems but also capable of addressing non-routine problems that demand reasoning and meaningful interconnections among concepts. This aligns with Maisaroh et al. (2025), who emphasized that mastery of concepts directly contributes to the improvement of students' scientific thinking skills and learning attitudes. Therefore, conceptual understanding is an important indicator in assessing the quality of mathematics learning in schools.

The importance of mathematical conceptual understanding is consistent with national education goals and curriculum demands that emphasize meaningful learning and the development of higher order thinking skills. Nasution (2019) asserted that mathematics learning should not only be oriented toward final results but also toward students' thinking processes in understanding concepts and relationships among them. The curriculum requires students to reason logically, systematically, and critically in solving both mathematical problems and contextual problems in daily life. However, various studies have shown that students' conceptual understanding remains relatively low, particularly in abstract topics that demand strong conceptual interconnections (Nurani et al., 2021; Martin et al., 2023). Rosiana et al. (2023) further revealed that weak conceptual understanding is caused by learning that does not fully integrate representation, procedure, and meaning. This lack of understanding is often marked by students' tendency to memorize problem-solving steps without comprehending the meaning behind the procedures used.

One of the mathematical topics that requires deep conceptual understanding is matrices. Matrix topics include various operations such as addition, subtraction, and multiplication, each with specific conditions and rules. Understanding matrix order, operation compatibility, and the meaning of each operation is essential for solving matrix problems correctly. Field observations show that many students still struggle to determine the appropriate matrix operation, understand operational requirements, and translate word problems into mathematical models in matrix form. Students' errors are generally caused by learning that emphasizes mechanical procedures without sufficient conceptual understanding (Pratama et al., 2024; Hermanto & Susilawati, 2023). Syahrir et al. (2025) found that learning which lacks visualization and conceptual interconnection leads to difficulties in understanding abstract mathematical concepts. Students often face conceptual barriers when mathematics learning is not accompanied by visual representation and reinforcement of conceptual meaning, particularly in symbolic and abstract topics (Oktama et al., 2026). Consequently, when students encounter problems slightly different from the given examples, they tend to become confused and make mistakes in determining solution steps.

Recent studies have also indicated that students' conceptual understanding can be strengthened through learning media that provide visual and interactive representations. Khusnunnisa & Andriani (2025) showed that interactive multimedia supported by augmented reality helps students connect abstract

concepts with concrete visual experiences. Similarly, Septiani et al. (2025) reported that augmented reality–integrated learning media effectively improve students' learning outcomes by enhancing conceptual clarity. In mathematics learning, visual-based instructional media were found to support students' numeracy and conceptual understanding by presenting mathematical ideas in more meaningful forms (Muti'ah et al., 2024). Gusmida & Islami (2017) further emphasized that augmented reality can function as a bridge between abstract concepts and students' mental representations. Moreover, differences in students' learning characteristics require instructional approaches that accommodate diverse ways of understanding concepts (Putri et al., 2025). These findings suggest that appropriate learning support and visualization play an important role in developing students' mathematical conceptual understanding.

Previous studies also revealed that students often solve matrix problems by memorizing steps without understanding the rationale behind them. Amanda et al. (2024) and Ramadhani et al. (2025) showed that students' errors in matrix topics are not only related to calculation but also to their inability to understand fundamental concepts such as the meaning of matrix order and the relationship between rows and columns in matrix multiplication. This indicates that conceptual understanding of matrices requires serious attention in secondary school mathematics learning, particularly in instruction that emphasizes the interconnection among concepts, procedures, and mathematical representations.

In addition to subject matter and teaching methods, students' individual characteristics also play an important role in determining success in learning mathematics. One such characteristic is learning style, which refers to individuals' tendencies in receiving, processing, and recalling information. Generally, learning styles are categorized into three types: visual, auditory, and kinesthetic (Ulum & Pujiastuti, 2020). Visual learners tend to understand concepts more easily through images, tables, and symbolic representations. Auditory learners comprehend concepts better through oral explanations, discussions, and verbal narration, while kinesthetic learners grasp concepts more effectively through direct activities, object manipulation, and physical learning experiences. Differences in learning styles affect how students understand and represent mathematical concepts, and instruction that does not consider learning styles may lead to misconceptions (Hasibuan et al., 2025). These differences indicate that each student has a unique way of building mathematical conceptual understanding. Putri et al. (2025) also emphasized that the diversity of students' learning characteristics requires adaptive teaching strategies to optimize conceptual understanding.

Several studies have shown a relationship between learning styles and students' mathematical conceptual understanding. Setiana et al. (2020) stated that students whose learning styles are well facilitated in instruction demonstrate more optimal conceptual understanding. Usman et al. (2022) also revealed that differences in learning styles result in distinct characteristics of conceptual understanding in mathematics, whether in representation, procedures, or conceptual explanations. A descriptive qualitative study is needed to provide a detailed description of students' thinking processes and conceptual understanding, particularly in topics that demand

strong interconnections among concepts such as matrices (Alqadri & Munawwarah, 2025). However, most previous studies have focused on quantitative analysis of conceptual understanding levels, while in-depth studies describing how students' conceptual understanding of matrices is characterized by their learning styles remain relatively limited. Yet, such detailed descriptions are crucial for helping teachers design instructional strategies that align with students' characteristics, as suggested by Wahyuni et al. (2025), who emphasized the importance of analyzing students' learning characteristics in instructional design.

Based on the above discussion, it can be concluded that mathematical conceptual understanding in matrix topics remains an issue that requires further investigation, particularly when viewed from differences in students' learning styles. This study is important not only to identify students' levels of conceptual understanding but also to reveal the characteristics of how students understand concepts based on their learning styles. Therefore, this research aims to describe students' mathematical conceptual understanding in solving matrix operations from the perspectives of visual, auditory, and kinesthetic learning styles. The findings are expected to provide theoretical contributions to the study of mathematical conceptual understanding and practical contributions for teachers in designing matrix instruction that accommodates the diversity of students' learning styles.

2. Methodology

This study employed a qualitative approach with a descriptive research design. This approach was chosen because the study aimed to obtain an in-depth understanding of the characteristics of students' mathematical conceptual understanding in solving matrix operations, viewed from visual, auditory, and kinesthetic learning styles. The descriptive design was used to provide a systematic, factual, and accurate description of the phenomenon under investigation without giving special treatment to the research subjects.

The subjects of this study were three Grade XI students from a senior high school, selected based on the results of a learning style questionnaire. The selection of subjects was carried out using purposive sampling, namely choosing students who represented each learning style category: one student with a visual learning style, one with an auditory learning style, and one with a kinesthetic learning style. Based on the questionnaire analysis, the subjects were identified as SF (visual), SFS (auditory), and PAN (kinesthetic). The selection also considered relatively equal academic abilities, based on recommendations from the mathematics teacher, so that differences in results would more accurately reflect differences in learning styles.

The research instruments consisted of a learning style questionnaire, a conceptual understanding test on matrix operations, and an interview guide. The questionnaire was used to classify students into visual, auditory, and kinesthetic categories. The conceptual understanding test was developed based on indicators of mathematical conceptual understanding, including the ability to restate concepts, classify objects

according to their properties, and represent problems in mathematical form. The test items were essay type questions, allowing students to write complete solution steps and demonstrate their thought processes. The interview guide was used to explore students' reasoning in applying certain strategies and to confirm the results of the written test. All instruments were validated through consultation with experts and mathematics teachers before use.

Data were collected through the administration of the learning style questionnaire, the conceptual understanding test on matrix operations, and in-depth interviews. The questionnaire was administered to determine each student's learning style category. After the research subjects were identified, they were given the written conceptual understanding test on matrix operations. Subsequently, semi structured interviews were conducted with each subject to obtain more detailed explanations of their thinking processes in solving problems and to clarify their written responses. All data collection procedures were carried out according to the school's learning schedule.

Data analysis referred to the qualitative data analysis model, which includes three stages: data condensation, data presentation, and conclusion drawing. In the data condensation stage, the researcher selected and focused the test and interview data according to the indicators of conceptual understanding. In the data presentation stage, the results of the analysis were presented in the form of narrative descriptions of the characteristics of each subject's conceptual understanding. In the conclusion drawing stage, the researcher interpreted the research findings based on the data analysis. To ensure data validity, technique triangulation was employed by comparing the results of the written test with the interview findings. The indicators of mathematical conceptual understanding used in this study were developed as the basis for constructing the test instrument on matrix operations. These indicators are presented in Table 1.

Table 1. Indicators of Conceptual Understanding

No	Indicator of Conceptual Understanding	Related Indicators in Matrix Addition, Subtraction, and Multiplication
1	Restating learned concepts	Explaining the definitions of matrix multiplication, addition, and subtraction
2	Classifying objects based on whether the requirements of the concept are met	Determining two matrices that can or cannot be added, subtracted, and multiplied
3	Presenting concepts in various forms of mathematical representation	Representing word problems of matrix multiplication into mathematical models

3. Results and Discussion

The findings indicate that each subject with a different learning style demonstrates distinct characteristics of mathematical conceptual understanding in solving matrix operations when viewed through the indicators of conceptual understanding. The subject SF, who has a visual learning style, showed strong ability in indicator (1) restating learned concepts, namely being able to explain the definitions of matrix

addition, subtraction, and multiplication in his/her own words. This can be seen in the written test results presented in Figure 1.

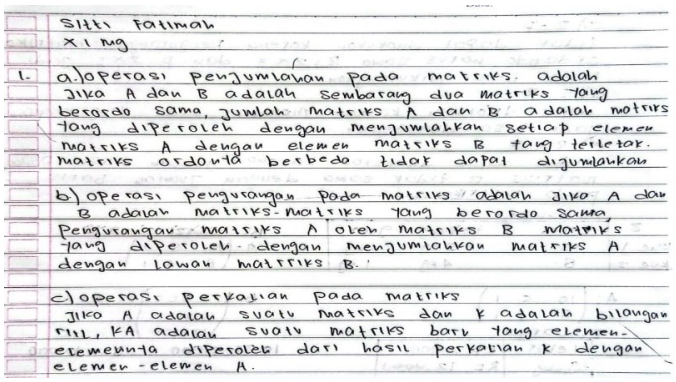

Figure 1. Written Test Results of Subject SF Related to Restating Learned Concepts

In indicator (2), classifying objects based on whether the requirements of matrix operations are met, subject SF was able to determine two matrices that can be added, subtracted, and multiplied by considering the compatibility of their orders. However, in indicator (3), presenting concepts in various forms of mathematical representation, subject SF still experienced difficulties in representing word problems into mathematical models in the form of matrices, as shown in the interview results presented in Table 2.

Table 2. Interview Transcript of Subject SF Related to Presenting Concepts in Various Forms of Mathematical Representation in Solving Matrix Operation Problems

		Dialogue
KN-095	Interviewer	Okay, let's continue to question number 3. After reading the word problem about making cakes, what information do you think is important to note first?
SF-096	Subject	The quantities of each ingredient for Cake I and Cake II, and the price of each ingredient.
KN-097	Interviewer	Which part of the problem can be transformed into mathematical form? Explain.
SF-098	Subject	The cake ingredients and their prices. The ingredients can be organized into a table, like this:

Ingredients Table

Ingredient	**Cake I**	**Cake II**
Eggs	10	8
Flour	5	4
Sugar	1	1

Price Table

Ingredient	**Price (Rp)**
Eggs	2,000
Flour	10,000
Sugar	12,000

KN-099	Interviewer	Then, how would the matrix form look?
SF-100	Subject	$A = \begin{bmatrix} 10 & 5 & 1 \\ 8 & 4 & 1 \end{bmatrix}, B = \begin{bmatrix} 2000 \\ 10000 \\ 12000 \end{bmatrix}$.
KN-101	Interviewer	Explain in your own words how you constructed the matrix from the cake ingredient data.
SF-102	Subject	First, I translated the word problem into mathematical form. Then I converted it into a matrix.
KN-103	Interviewer	What did you place as rows and what as columns in the matrix? Why?
SF-104	Subject	Cake I (10 eggs, 5 kg flour, 1 kg sugar) is the first row, and Cake II (8 eggs, 4 kg flour, 1 kg sugar) is the second row. The first column is eggs, the second column is flour, and the third column is sugar.
KN-105	Interviewer	If asked to explain the meaning of each row and column in the matrix you created, how would you explain it?
SF-106	Subject	Same as before: Cake I ingredients form the first row, Cake II ingredients form the second row. Columns represent eggs, flour, and sugar respectively.
KN-107	Interviewer	How would you represent the prices of eggs, flour, and sugar mathematically?
SF-108	Subject	Like this: Eggs = Rp2,000; Flour = Rp10,000; Sugar = Rp12,000.
KN-109	Interviewer	What matrix form is most appropriate to represent the price data? Explain your reasoning.
SF-110	Subject	A 3×1matrix, like this: $\begin{bmatrix} 2000 \\ 10000 \\ 12000 \end{bmatrix}$.
KN-111	Interviewer	How are the ingredient matrix and the price matrix related in cost calculation?
SF-112	Subject	Without matrices, the calculation can be done one by one, but using matrices is neater and faster.
KN-113	Interviewer	Explain the process of calculating the total cost using matrices, without directly stating the final result.
SF-114	Subject	For Cake I: $10 \times 2000 + 5 \times 10000 + 1 \times 12000 = 82{,}000$. For Cake II: $8 \times 2000 + 4 \times 10000 + 1 \times 12000 = 68{,}000$. So, $C = \begin{bmatrix} 82000 \\ 68000 \end{bmatrix}$.
KN-115	Interviewer	What matrix operation did you use to solve this problem? Why?
SF-116	Subject	Multiplication. I chose matrix multiplication because the quantities are in a matrix and the prices are in a column matrix. Multiplying them directly gives the cost of each cake.
KN-117	Interviewer	If not using matrices, what other method could be used? Compare it with the matrix method.
SF-118	Subject	Without matrices, I would calculate each ingredient cost separately and then sum them. This method is simpler but less practical if the data is large. Using matrices is more systematic and efficient.
KN-119	Interviewer	What are the advantages of using matrices for solving word problems like this?
SF-120	Subject	It's faster and less complicated, especially when dealing with large amounts of data.
KN-121	Interviewer	If the number of cake types or ingredients increases, would the matrix representation change?
SF-122	Subject	Yes, the number of rows or columns would increase depending on whether more cake types or ingredients are added.
KN-123	Interviewer	How do you ensure that the matrix model you created matches the word problem?
SF-124	Subject	I check the data one by one to make sure it matches the problem and produces logical results.

This indicates that subject SF excels in symbolic representation and mastery of definitions but still requires guidance in connecting matrix concepts to contextual

problems. These findings are consistent with Setiana et al. (2020), who stated that students with a visual learning style tend to understand concepts through images, tables, and mathematical symbols, yet are not necessarily able to directly relate them to contextual problems. Subject SFS, who has an auditory learning style, demonstrated strong ability in indicator (1) restating concepts, namely being able to orally explain the definitions of matrix addition, subtraction, and multiplication in a structured manner. This was evident in the written test results presented in Figure 2 and further supported by the interview findings shown in Table 3.

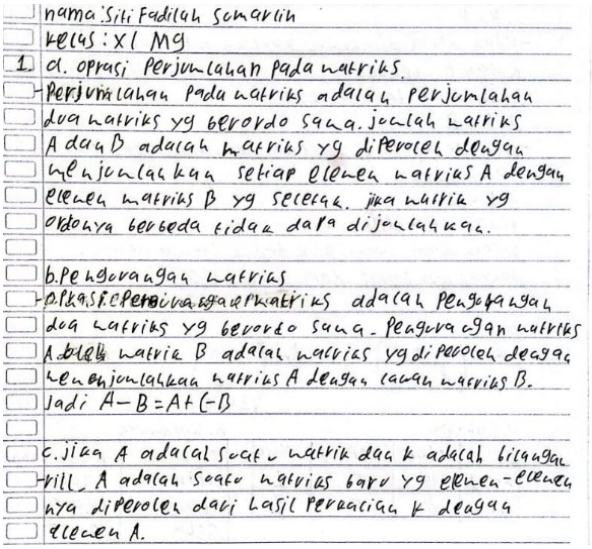

Figure 2. Written Test Results of Subject SFS Related to Restating Learned Concepts in Solving Matrix Operation Problems

Table 3. Interview Transcript of Subject SFS Related to Restating Learned Concepts in Solving Matrix Operation Problems

		Dialogue
KN-013	Interviewer	In your opinion, what is matrix addition?
SFS-014	Subject	Matrix addition is an operation to add two matrices by summing the numbers in the same positions.
KN-015	Interviewer	When asked to add two matrices, what do you pay attention to first?
SFS-016	Subject	The first thing I check is the size of the matrices; they must be the same to be added.
KN-017	Interviewer	Explain in your own words how the process of matrix addition works.
SFS-018	Subject	The numbers in the same rows and columns are added one by one, and the results are arranged into a new matrix.
KN-019	Interviewer	When can two matrices be added?
SFS-020	Subject	Two matrices can be added if they have the same number of rows and columns.
KN-021	Interviewer	Why can’t two matrices of different sizes be added?
SFS-022	Subject	Because if the sizes are different, the positions of the numbers don’t match, so they can’t be added.
KN-023	Interviewer	Do you think matrix addition is similar to ordinary addition? Explain.
SFS-024	Subject	It’s similar to ordinary addition, but here the numbers are added position by position in the matrix.
KN-025	Interviewer	Now about matrix subtraction, what do you know about this operation?
SFS-026	Subject	Matrix subtraction is almost the same as addition, except the numbers are subtracted.

KN-027	Interviewer	How do you understand matrix subtraction?
SFS-028	Subject	I understand matrix subtraction by subtracting the numbers in the same positions of the two matrices.
KN-029	Interviewer	Are the rules for matrix subtraction the same as for matrix addition? Why?
SFS-030	Subject	The rules are the same; the sizes must also be the same. The only difference is the operation used.
KN-031	Interviewer	What is the main difference between matrix addition and subtraction?
SFS-032	Subject	The difference is only in the operation sign: one is addition, the other is subtraction.
KN-033	Interviewer	Which part of matrix subtraction often causes confusion?
SFS-034	Subject	What often causes confusion is when the result is negative.
KN-035	Interviewer	If the result of matrix subtraction is negative, what does that mean?
SFS-036	Subject	If the result is negative, it means the number in the second matrix is larger than in the first.
KN-037	Interviewer	Now about matrix multiplication, in general, what is matrix multiplication?
SFS-038	Subject	Matrix multiplication is an operation where the result is obtained by multiplying certain rows and columns.
KN-039	Interviewer	What distinguishes matrix multiplication from addition or subtraction?
SFS-040	Subject	The difference is that matrix multiplication has special conditions; it can't just be done like addition.
KN-041	Interviewer	If you were to explain matrix multiplication to a friend, how would you do it?
SFS-042	Subject	I would explain that the rows of the first matrix are multiplied by the columns of the second matrix, then summed.
KN-043	Interviewer	What do you mean by "row multiplied by column"?
SFS-044	Subject	It means each number in a row is multiplied by the corresponding number in a column.
KN-045	Interviewer	Why can't all matrices be multiplied?
SFS-046	Subject	Because the number of columns in the first matrix must equal the number of rows in the second matrix.
KN-047	Interviewer	What happens if the order of matrix multiplication is reversed?
SFS-048	Subject	If the order is reversed, the result can be different or sometimes the multiplication cannot be done.
KN-049	Interviewer	What does the result of matrix multiplication usually represent?
SFS-050	Subject	The result of matrix multiplication usually shows the relationship between two sets of data.
KN-051	Interviewer	Which matrix operation do you understand best? Why?
SFS-052	Subject	I understand matrix addition best because the process is simple.
KN-053	Interviewer	Which matrix operation do you find most difficult? Why?
SFS-054	Subject	Matrix multiplication is the most difficult for me because the steps are longer.
KN-055	Interviewer	What do you usually do when you feel confused while solving matrix problems?
SFS-056	Subject	I usually look at example problems again or ask a friend.
KN-057	Interviewer	In your opinion, how should teachers explain matrices so they are easier to understand?
SFS-058	Subject	If teachers explain slowly using real life examples, it's easier to understand.

In indicator (2), classifying objects based on whether the requirements of matrix operations are met, subject SFS was able to determine pairs of matrices that can be operated on and those that cannot. However, in indicator (3), presenting concepts in the form of mathematical representation, subject SFS was still inconsistent in modeling word problems into matrix form and often made calculation errors. These findings indicate that subject SFS is stronger in verbal ability to explain concepts than in accuracy when applying mathematical procedures. This result is consistent

with Usman et al. (2022), who stated that auditory learners excel in mathematical communication but require further guidance in procedural aspects.

Meanwhile, subject PAN, who has a kinesthetic learning style, demonstrated good conceptual understanding across all three indicators of conceptual comprehension. In indicator (1), restating concepts, subject PAN was able to correctly explain the definitions of matrix operations. In indicator (2), classifying objects, subject PAN was able to determine two matrices that can be added, subtracted, and multiplied by considering the order requirements of matrices. Furthermore, in indicator (3), presenting concepts in the form of mathematical representation, subject PAN was able to accurately model word problems into matrix based mathematical models, as shown in the written test results presented in Figure 3 and supported by the interview findings in Table 4.

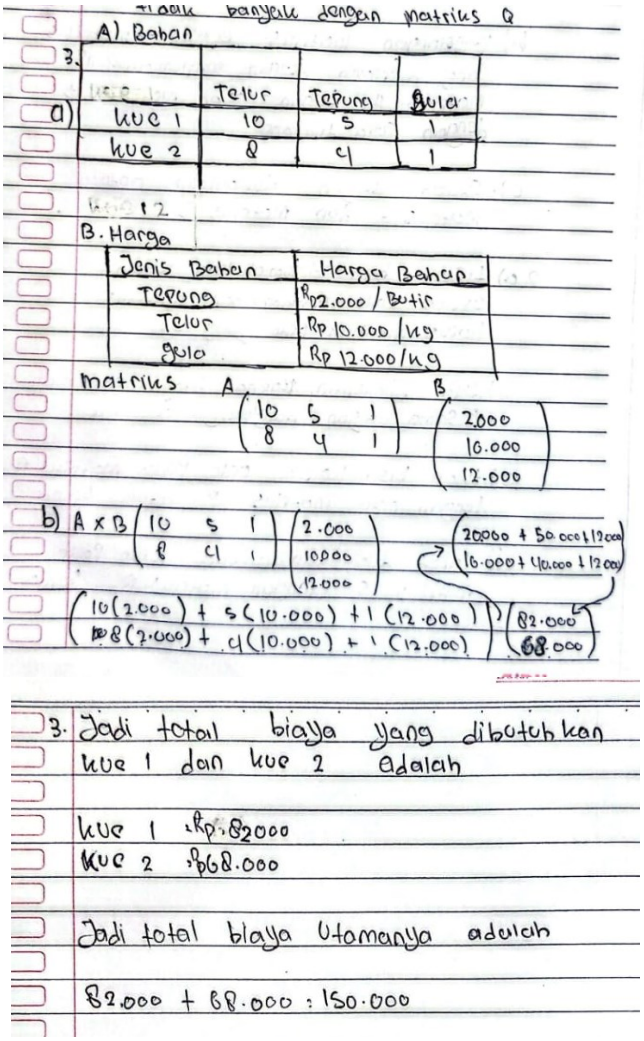

Figure 3. Written Test Results of Subject PAN Related to Presenting Concepts in Various Forms of Mathematical Representation in Solving Matrix Operation Problems

Table 4. Interview Transcript of Subject PAN Related to Presenting Concepts in Various Forms of Mathematical Representation in Solving Matrix Operation Problems

		Dialogue
KN-095	Interviewer	Okay, let's continue to question number 3. After reading the word problem about making cakes, what information do you think is important to note first?
PAN-096	Subject	The quantities of ingredients for each cake and the price of the ingredients.
KN-097	Interviewer	Which part of the problem can be transformed into mathematical form? Explain.
PAN-098	Subject	The quantities of ingredients and their prices can be transformed into matrices.
KN-099	Interviewer	Why do you think the problem in this question can be represented using matrices?
PAN-100	Subject	Because it involves structured data that can be calculated systematically.
KN-101	Interviewer	Explain in your own words how you constructed the matrix from the cake ingredient data.
PAN-102	Subject	I constructed the matrix based on the types of cakes and the ingredients.
KN-103	Interviewer	What did you place as rows and what as columns in the matrix? Why?
PAN-104	Subject	Rows represent the types of cakes, columns represent the ingredients.
KN-105	Interviewer	If asked to explain the meaning of each row and column in the matrix you created, how would you explain it?
PAN-106	Subject	Each row represents one type of cake, each column represents an ingredient.
KN-107	Interviewer	How did you represent the prices of eggs, flour, and sugar mathematically?
PAN-108	Subject	I represented them in the form of a price matrix.
KN-109	Interviewer	What matrix form is most appropriate to represent the price data? Explain your reasoning.
PAN-110	Subject	A column matrix, because it is simpler.
KN-111	Interviewer	How are the ingredient matrix and the price matrix related in cost calculation?
PAN-112	Subject	They are related through matrix multiplication.
KN-113	Interviewer	Explain the process of calculating the total cost using matrices, without directly stating the final result.
PAN-114	Subject	By multiplying the ingredient matrix with the price matrix.
KN-115	Interviewer	What matrix operation did you use to solve this problem? Why did you choose that operation?
PAN-116	Subject	Matrix multiplication, because it is used to calculate the total cost.
KN-117	Interviewer	If not using matrices, what other method could be used to solve this problem? Compare it with the matrix method.
PAN-118	Subject	It can be solved by calculating one by one, but using matrices is faster.
KN-119	Interviewer	What are the advantages of using matrices to solve word problems like this?
PAN-120	Subject	It is neater and more efficient.
KN-121	Interviewer	If the number of cake types or ingredients increases, would the matrix representation change?
PAN-122	Subject	Yes, the size of the matrix would increase.
KN-123	Interviewer	How do you ensure that the matrix model you created matches the word problem?
PAN-124	Subject	I cross check it again with the word problem.

These findings indicate that active involvement in the problem-solving process helped subject PAN develop a more meaningful conceptual understanding. This result is consistent with Ulum and Pujiastuti (2020), who stated that kinesthetic

learners tend to understand concepts through direct activities and object manipulation.

When viewed as a whole based on the indicators of conceptual understanding, subjects SF and SFS fulfilled indicators (1) and (2), but still experienced difficulties with indicator (3), namely presenting word problems into mathematical models in the form of matrices. In contrast, subject PAN consistently demonstrated fulfillment of all three indicators of conceptual understanding. These findings reinforce the view that mathematical conceptual understanding is not singular but varies according to students' learning style tendencies. This aligns with Mawaddah and Maryanti (2016), who stated that mathematical conceptual understanding includes the ability to restate concepts, classify objects, and represent concepts in problem-solving.

Theoretically, the results of this study can be explained through learning style theory, which states that each individual has certain preferences in processing information (Ulum & Pujiastuti, 2020). These preferences influence how students construct meaning of the mathematical concepts they learn. When instructional strategies align with students' learning styles, the process of conceptual understanding becomes more optimal. Conversely, if instructional strategies do not align with students' learning style tendencies, the conceptual understanding formed tends to be less profound and merely procedural. Thus, the findings of this study emphasize the importance of teaching that considers the diversity of learning styles in order to improve the quality of students' mathematical conceptual understanding, particularly in matrix operations, which demand accuracy and interconnection among concepts.

Furthermore, the differences in students' conceptual understanding based on learning styles can be interpreted through the way each learner processes and organizes information when solving matrix operation problems. Visual learners tend to rely on structured representations such as tables, matrices, and symbolic forms to understand relationships among elements. This explains why subject SF demonstrated strength in defining and arranging matrix elements but experienced difficulty when required to translate contextual word problems into mathematical models. The transition from verbal or narrative information to symbolic representation requires not only visualization skills but also the ability to connect real-life situations with abstract mathematical structures. Without sufficient scaffolding, visual learners may focus more on the appearance of symbols than on the meaning underlying the representation.

In contrast, auditory learners construct understanding mainly through verbal explanation and sequential reasoning. Subject SFS showed strong performance in explaining the concepts of matrix operations orally and in restating procedural rules. However, inconsistencies in calculation accuracy and representation suggest that verbal comprehension alone is not sufficient to guarantee correct procedural execution. This finding supports the view that auditory learners benefit significantly from interactive discussions and step-by-step verbal guidance, but still require visual or written reinforcement to strengthen their procedural fluency. The

mismatch between verbal explanation and written representation may lead to errors when students are required to independently construct mathematical models from word problems.

Kinesthetic learners, as represented by subject PAN, demonstrated more balanced conceptual understanding across all indicators. This can be attributed to their tendency to learn through direct involvement in problem-solving activities and manipulation of mathematical objects or representations. By actively constructing matrices from contextual data and performing matrix operations step by step, kinesthetic learners are more likely to internalize both the meaning and the procedure of mathematical concepts. This supports constructivist learning theory, which emphasizes that knowledge is built through active engagement and personal experience rather than passive reception of information. When students are involved in constructing models and verifying results through action, their conceptual understanding becomes more stable and transferable to new problem situations.

These findings imply that instructional strategies in matrix learning should not rely on a single mode of explanation but should integrate visual, auditory, and kinesthetic elements. For example, teachers may introduce matrix concepts using visual representations such as tables or diagrams, reinforce them through verbal explanation and classroom discussion, and strengthen understanding through hands-on activities such as constructing matrices from real-life data or solving contextual problems collaboratively. Such multimodal instruction not only accommodates differences in learning styles but also helps students build stronger connections between abstract symbols and their practical meanings. Consequently, learning that integrates multiple representational forms is more likely to promote deep and flexible conceptual understanding of matrix operations.

Although this study provides insights into the characteristics of mathematical conceptual understanding based on learning styles, it has several limitations. First, the number of research subjects was limited to three students representing each category of visual, auditory, and kinesthetic learning styles, so the findings cannot yet be generalized to a larger student population. Second, the study was conducted in one school context and focused on one topic, namely matrix operations, so the characteristics of conceptual understanding found are likely influenced by the learning environment and the curriculum applied in that school. Third, the descriptive qualitative design of the study means that the findings emphasize the depth of analysis of students' thinking processes rather than quantitative measurement of achievement levels. Therefore, future research is recommended to involve a larger number of subjects, employ more varied research designs, and examine other mathematical topics to obtain a more comprehensive picture of the relationship between learning styles and students' mathematical conceptual understanding.

4. Conclusion

Based on the results of the study, it can be concluded that students' conceptual understanding of matrix operations demonstrates different characteristics when viewed from the perspective of learning styles. Students with a visual learning style tend to understand concepts through table representations and the organization of matrix elements. Students with an auditory learning style show strength in verbally explaining concepts, while students with a kinesthetic learning style develop understanding more effectively through direct activities and mathematical modeling. The findings indicate that the research objective of describing students' conceptual understanding of matrix operations based on visual, auditory, and kinesthetic learning styles has been successfully achieved. These results confirm that learning style differences influence how students restate concepts, classify matrix operations, and represent problems in mathematical form. This study implies that matrix instruction should be designed using adaptive and varied strategies that accommodate students' learning style characteristics in order to foster optimal conceptual understanding. Further research is recommended to involve a larger number of participants and to explore other mathematical topics so that a more comprehensive understanding of the relationship between learning styles and mathematical conceptual understanding can be obtained.

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