

From words to matrices: uncovering students' errors in solving contextual matrix algebra problems

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Received: June 13, 2026 | **Revised:** Sept 25, 2026 | **Accepted:** Sept 28, 2026 | **Published Online:** Sept 30, 2026

Abstract

Contextual problems in matrix algebra require students not only to perform matrix operations but also to construct mathematical models and interpret results meaningfully. However, many students encounter difficulties when translating real-world situations into matrix representations. This study aims to identify the types of errors students make when solving contextual matrix algebra problems and to explore the underlying factors contributing to these errors. Employing a qualitative descriptive design, the study involved sixteen Mathematics Education students who had completed a Matrix Algebra course. Data were collected through contextual matrix algebra tests and semi-structured interviews. Data were analyzed using methodological triangulation. The results revealed four categories of errors: conceptual, mathematical modeling, procedural, and interpretation. Mathematical modeling errors emerged as the most dominant category, particularly in constructing matrix representations and determining the appropriate order of matrix operations. Conceptual errors were associated with misconceptions about matrix structures and operations, whereas procedural errors involved calculation inaccuracies. Interpretation errors occurred when students failed to connect mathematical results to the problem's context. These findings indicate that students' difficulties extend beyond computational skills and are closely related to their ability to understand, model, and interpret contextual situations mathematically. Therefore, instructional practices should emphasize contextual problem-solving and mathematical modeling to foster deeper conceptual understanding and higher-order thinking skills in learning matrix algebra.

Keywords: contextual problems; error analysis; mathematical modeling errors; matrix algebra

How to Cite: Rahmasari, S.M., Nurrasa, S., Nalim, Alam, M.M. (2026). From words to matrices: uncovering students' errors in solving contextual matrix algebra problems. *Aksioma: Jurnal Matematika dan Pendidikan Matematika*, 17 (2), 323-336. <https://doi.org/10.26877/wr9rnz46>

INTRODUCTION

Matrix algebra is a fundamental topic in mathematics that plays an essential role in various fields, including economics, engineering, statistics, computer science, and data analysis. Mastery of matrix concepts requires not only the ability to perform mathematical operations procedurally but also the ability to represent real-world problems using appropriate mathematical models. In higher-education mathematics learning, students are

expected to connect abstract mathematical concepts to contextual situations to solve real-life problems.

The ability to solve contextual problems is an integral component of Higher Order Thinking Skills (HOTS), which involves analyzing, evaluating, and creating solutions to given problems. According to Irfan et al. (2022), solving HOTS-oriented problems requires students to integrate conceptual understanding, mathematical reasoning, and decision-making skills in non-routine situations. Therefore, contextual problems assess not only computational abilities but also students' ability to construct mathematical models and interpret the results. International discourse affirms that word problems inherently demand a complex cognitive shift from textual comprehension to structural mathematical modeling, a phase where students universally struggle (Verschaffel et al., 2020).

Nevertheless, numerous studies have shown that students continue to experience difficulties solving contextual mathematical problems. Laman et al. (2020) found that students' errors in solving HOTS problems include errors in understanding the problem, conceptual errors, procedural errors, and errors in concluding. These findings indicate that higher-order thinking skills have not been fully developed, even though students have learned the necessary mathematical concepts.

Similar issues have also been identified in matrix-related topics. Hasbi et al. (2023) reported that students still encounter difficulties in understanding fundamental matrix concepts, determining appropriate operations, and performing calculations correctly. Furthermore, Wahyudi et al. (2023) revealed that errors in matrix topics are not limited to computational mistakes but also involve misunderstandings of the relationships among concepts required for problem-solving. These findings suggest that procedural mastery alone does not guarantee students' ability to apply matrix concepts to solve more complex problems.

On the other hand, most studies on error analysis in matrix learning have focused on routine problems that emphasize procedural aspects. In contextual problems, however, students are required to translate verbal information into appropriate mathematical models. When the modeling process is not carried out correctly, subsequent solution steps will also lead to incorrect answers. For example, students frequently make errors in determining the correct order of matrix multiplication in a given problem context. Such

errors indicate that students face not only procedural difficulties but also obstacles in understanding the mathematical meaning of the representations being used.

Research on mathematical error analysis has widely employed Newman's Error Analysis framework to identify the stages at which students make mistakes across various mathematical domains, ranging from elementary fractions and statistics to ethnomathematics (Paramarta, 2025; Rohalia, 2026; Ummah, 2025). Lubis et al. (2025) explained that errors may occur at the stages of reading, comprehension, transformation, process skills, and encoding the final answer. Meanwhile, Sarah et al. (2023) found that errors in transformation and process skills are the most common when solving HOTS problems. However, these classifications remain relatively general and insufficiently detailed to explain the specific errors that arise in matrix algebra, particularly those related to mathematical modeling.

Based on the literature reviewed, a research gap remains: the limited number of studies that specifically investigate students' errors in solving contextual matrix algebra problems while simultaneously examining conceptual, mathematical modeling, procedural, and interpretative aspects. Therefore, this study proposes a more specific error-classification framework to provide a deeper understanding of students' thinking processes when solving contextual matrix algebra problems.

The four error categories in this study are synthesized from established perspectives on mathematical knowledge, mathematical modeling, and error analysis. Conceptual errors relate to students' understanding of mathematical concepts, while mathematical modeling errors concern difficulties in translating contextual situations into appropriate mathematical representations. Procedural errors refer to mistakes in applying mathematical procedures or operations, consistent with the distinction between conceptual and procedural knowledge. Interpretative errors involve difficulties in relating mathematical results back to the original context, reflecting the interpretation and validation stages of the modeling process. Thus, these four categories provide a contextualized synthesis that extends general error-analysis frameworks, such as Newman's Error Analysis, to capture students' difficulties in solving contextual matrix algebra problems.

This study aims to identify the types of errors students make when solving contextual matrix algebra problems and to reveal the factors contributing to these errors.

The findings are expected to serve as a basis for developing instructional strategies that can enhance students' mathematical modeling and problem-solving abilities in matrix algebra.

METHODS

This study employed a qualitative approach with a descriptive research design. A qualitative approach was selected because the study aimed to gain an in-depth understanding and description of the types of errors students make when solving contextual matrix algebra problems, as well as the factors contributing to these errors. According to Creswell & Creswell (2018), qualitative research is used to explore and understand the meanings that individuals or groups ascribe to social or educational problems. Similarly, qualitative research aims to produce systematic descriptions of phenomena based on data obtained directly from research participants.

The study was conducted with students of the Mathematics Education Program who had completed the Linear Algebra course. Sixteen students were selected as participants through purposive sampling based on their performance on a contextual matrix algebra problem-solving test. According to Patton (2015), purposive sampling enables researchers to select participants who are considered capable of providing the most relevant information regarding the research objectives. Based on the test results, participants were selected from high, medium, and low-achievement groups to obtain a more comprehensive representation of students' errors.

In this study, the researcher served as the primary research instrument, as is characteristic of qualitative research (Lincoln & Guba, 1985). The researcher was involved in all stages of the study, including instrument development, data collection, data analysis, and conclusion drawing. In addition to the researcher, the research instruments consisted of a contextual matrix algebra test and a semi-structured interview protocol. The test instrument was developed based on indicators of mathematical modeling ability and matrix operations, encompassing conceptual, modeling, procedural, and interpretative aspects.

The data were collected through written tests and in-depth interviews. The written test was administered to identify the types of errors students made when solving contextual matrix algebra problems. Subsequently, in-depth interviews were conducted

to explore students' thought processes and the factors underlying their errors. According to Merriam & Tisdell (2016), interviews are an effective technique for obtaining information about participants' experiences, understandings, and thought processes that cannot be directly observed.

The validity of the data was established through methodological triangulation and member checking. Methodological triangulation was achieved by comparing data from written tests and interviews to ensure consistency and credibility. It is argued that triangulation is an important strategy for enhancing the validity of qualitative research findings by using multiple data sources or data collection techniques. In addition, member checking was employed by asking participants to verify the researcher's interpretations of their responses and interview statements.

Data analysis was conducted interactively following the model proposed by Miles et al. (2014), which consists of data reduction, data display, and conclusion drawing. During the data reduction stage, students' errors were identified and categorized into four types: conceptual, mathematical modeling, procedural, and interpretation. The categorized data were then presented in tables and narrative descriptions to facilitate interpretation. Finally, conclusions were drawn regarding the emerging patterns of error and the factors contributing to students' difficulties in solving contextual matrix algebra problems.

RESULTS AND DISCUSSION

An analysis of students' responses to contextual matrix algebra problems revealed four main categories of errors: conceptual, mathematical modeling, procedural, and interpretation. These categories were identified based on an analysis of students' written assignments and interview data. The error categories were also based on the most common errors students made. The distribution of these errors is presented in Table 1.

Table 1. Distribution of Students' Errors

Error Types	Number of Students	Percentage (%)
Conceptual Errors	3	18.75%
Mathematical Modeling Errors	6	37.5%
Procedural Errors	3	18.75%

Interpretation Errors	4	25%
Total	16	100%

The results indicate that mathematical modeling errors were the most dominant type of error, followed by interpretation, conceptual, and procedural errors. This finding suggests that students experienced greater difficulty in translating contextual information into mathematical representations than in performing matrix operations.

1. Conceptual Errors

Conceptual errors were identified when students failed to understand the fundamental concept of matrix multiplication despite correctly recognizing the dimensions of the matrices involved. Figure 1 illustrates a representative example of this type of error.

Handwritten student work showing two matrix multiplication problems. In both, a 3×3 matrix is multiplied by a 3×1 vector, but the student incorrectly produces a 3×3 matrix result instead of a 3×1 vector.

Problem 1:

$$\begin{bmatrix} 1,1 & 0,1 & 0 \\ 0 & 1,2 & 0,1 \\ 0,1 & 0 & 1,3 \end{bmatrix} \cdot \begin{bmatrix} 100 \\ 150 \\ 200 \end{bmatrix} = \begin{bmatrix} 11,0 & 1,5 & 0 \\ 0 & 1,8 & 1,5 \\ 0,2 & 0 & 2,6 \end{bmatrix}$$

Problem 2:

$$\begin{bmatrix} 0,9 & 0 & 0 \\ 0 & 0,85 & 0 \\ 0 & 0 & 0,8 \end{bmatrix} \cdot \begin{bmatrix} 100 \\ 150 \\ 200 \end{bmatrix} = \begin{bmatrix} 9,0 & 0 & 0 \\ 0 & 12,75 & 0 \\ 0 & 0 & 16,0 \end{bmatrix}$$

Figure 1. Students' Response Indicating Conceptual Errors

In the contextual investment problem, students were required to determine the final investment value by multiplying a 3×3 growth matrix with a 3×1 investment vector. As shown in Figure 1, the student correctly identified that the matrices were dimensionally compatible for multiplication. However, instead of performing the row-by-column dot product required in matrix multiplication, the student multiplied each matrix entry directly by the corresponding element of the investment vector. Consequently, the student produced a 3×3 matrix rather than the correct 3×1 result.

This response indicates that the student misunderstood the fundamental mechanism of matrix multiplication. Rather than viewing matrix multiplication as a linear transformation in which each entry of the resulting vector is obtained by summing the products of corresponding elements in a row and a column, the student treated the operation as element-wise multiplication. Such reasoning demonstrates a

misconception regarding the definition of matrix multiplication rather than a computational mistake.

Interview data further revealed that the student believed each element of the matrix could be multiplied directly by the corresponding element of the investment vector because both matrices had the same number of rows. This explanation suggests that the student was unable to distinguish matrix multiplication from element-wise multiplication. Therefore, the error is classified as a conceptual error rather than a procedural error, since the misconception originated from an incorrect understanding of the underlying mathematical concept rather than from an arithmetic inaccuracy.

These findings are consistent with Hasbi et al. (2023), who reported that students frequently have difficulty understanding the fundamental concepts of matrix operations. Likewise, Wahyudi et al. (2023) argued that misconceptions regarding matrix operations often become the primary source of subsequent errors in solving matrix-related problems. The present study extends these findings by showing that in contextual matrix algebra problems, conceptual misunderstandings can lead students to produce mathematically invalid representations, even when they correctly recognize the matrix dimensions.

2. Mathematical Modeling Errors

Mathematical modeling errors were the most frequently observed category. These errors occurred when students failed to translate contextual information into mathematical models that accurately represented the problem's situation. Figure 2 illustrates a representative example of this type of error.

No. _____
Date: _____

☐	b. <u>sebelum</u>						
☐	$R \cdot V =$	$\begin{bmatrix} 0.9 & 0 & 0 \\ 0 & 0.85 & 0 \\ 0 & 0 & 0.8 \end{bmatrix}$	$\begin{bmatrix} 100 \\ 150 \\ 200 \end{bmatrix}$	$=$	$\begin{bmatrix} 90 + 0 + 0 \\ 0 + 127.5 + 0 \\ 0 + 0 + 160 \end{bmatrix}$	$=$	$\begin{bmatrix} 90 \\ 127.5 \\ 160 \end{bmatrix}$
☐							
☐							
☐							

Figure 2. Students' Response Indicating a Modeling Error

In the contextual investment task, students were asked to compare the investment value before and after risk adjustment. As shown in Figure 2, the student labeled the

calculation as "before risk adjustment," yet the mathematical model applied was RV , where R denotes the risk adjustment matrix, and V represents the initial investment vector. This operation actually produces the investment value after risk adjustment. Although the matrix multiplication was performed correctly, the model did not align with the problem's contextual meaning.

This finding indicates that the student was able to identify the required matrix operation but failed to associate the mathematical model with the appropriate stage of the investment process. Rather than analyzing the sequence of events presented in the problem, the student treated the risk adjustment matrix merely as another matrix to be multiplied by the investment vector. As a result, the mathematical representation did not accurately reflect the real-world context, leading to an incorrect interpretation of the solution.

This type of error demonstrates that successful problem solving in contextual matrix algebra requires more than procedural competence. Students must also understand the role and meaning of each matrix within the given context and construct mathematical models that faithfully represent the sequence of events described in the problem. The findings support previous studies reporting that students often experience difficulties during the transformation stage of contextual problem solving, in which verbal information must be translated into an appropriate mathematical representation (Lubis et al. 2025). However, the present study further shows that modeling errors may still occur even when students correctly perform the required matrix operations, indicating that contextual interpretation constitutes a distinct challenge in matrix algebra problem solving.

This finding is consistent with Newman's transformation error stage, where students fail to convert a verbal problem into an appropriate mathematical representation (Lubis et al. 2025). Recent studies employing Newman's framework corroborate that translating verbal information into mathematical models consistently remains the most challenging hurdle for students across different problem contexts (Paramarta, 2025; Rohalia, 2026). However, the present study demonstrates that in matrix algebra, transformation errors are closely associated with difficulties in mathematical modeling, particularly in determining the structure and order of matrix

operations. These results suggest that students require greater exposure to contextual modeling activities rather than routine computational exercises.

3. Procedural Errors

Procedural errors occurred when students correctly understood the problem and selected an appropriate model, but made mistakes during the calculation. The most common procedural error involved incorrect matrix multiplication. Arithmetic inaccuracies were observed, even when students applied the correct procedure. Figure 3 presents an example of a procedural error identified in students' solutions when performing matrix operations.

a. Distribusi Rand

$$\bar{D} + R = \begin{bmatrix} 10 & 5 & 8 \\ 6 & 7 & 9 \\ 4 & 3 & 5 \end{bmatrix} + \begin{bmatrix} -2 & 1 & 0 \\ 1 & -1 & 2 \\ 0 & 2 & -1 \end{bmatrix} = \begin{bmatrix} 8 & 6 & 8 \\ 7 & 6 & 11 \\ 4 & 5 & 4 \end{bmatrix}$$

b. total biaya sbm dan sesudah perubahan

$$\bar{D}_{lama} \cdot T = \begin{bmatrix} 10 & 5 & 8 \\ 6 & 7 & 9 \\ 4 & 3 & 5 \end{bmatrix} \cdot \begin{bmatrix} 3 & 2 & 4 \\ 5 & 1 & 2 \\ 4 & 3 & 1 \end{bmatrix} = \begin{bmatrix} 87 & 49 & 55 \\ 85 & 46 & 47 \\ 47 & 26 & 27 \end{bmatrix}$$

$$\bar{D}_{baru} \cdot T = \begin{bmatrix} 8 & 6 & 8 \\ 7 & 6 & 11 \\ 4 & 5 & 4 \end{bmatrix} \cdot \begin{bmatrix} 3 & 2 & 4 \\ 5 & 1 & 2 \\ 4 & 3 & 1 \end{bmatrix} = \begin{bmatrix} 86 & 46 & 52 \\ 95 & 53 & 37 \\ 53 & 25 & 30 \end{bmatrix}$$

Figure 3. Student's Response Indicating a Procedural Error

As shown in Figure 3, the student correctly constructed the required mathematical expression and applied the appropriate procedure for matrix multiplication. The dimensions of the matrices were compatible, and the multiplication process followed the row-by-column rule. However, an error occurred during the computation of the element in the first row and third column of the resulting matrix. The student obtained a value of 55, whereas the correct calculation is $10(4) + 5(2) + 8(1) = 40 + 10 + 8 = 58$.

This finding indicates that the student understood both the mathematical model and the algorithm for matrix multiplication but failed to execute the numerical calculation accurately. Therefore, the error did not stem from misconceptions about

matrix operations or from an incorrect mathematical representation of the contextual problem. Instead, it resulted from an error in the calculation procedure.

Interview data revealed that these errors were primarily due to a lack of accuracy and insufficient mastery of matrix operations procedures. Students often rushed through calculations and rarely checked their work. This finding aligns with the results reported by Sarah et al., (2023). who found that process-skill errors are among the most common in solving higher-order thinking problems. Although procedural errors were not the most dominant category in the present study, they contributed significantly to incorrect final answers. These findings indicate that procedural fluency remains important and should be developed alongside conceptual understanding and mathematical modeling skills.

4. Interpretation Errors

Interpretation errors occurred when students were unable to explain the meaning of their mathematical results within the context of the problem. Figure 4 presents an example of an interpretation error identified in students' responses to the contextual investment problem.

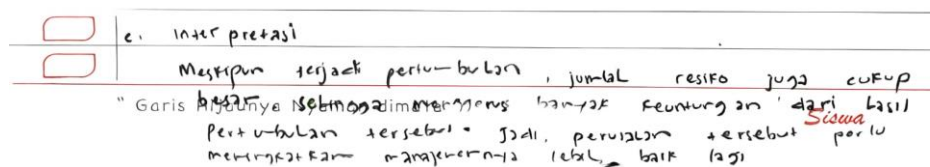


Figure 4. Students' Response Indicating an Interpretation Error

As shown in Figure 4, the student stated that although investment growth occurred, the level of risk was sufficiently high to reduce the overall profit and concluded that the company should improve its management practices. While the response appears reasonable in everyday language, the interpretation was not supported by the mathematical results obtained from the matrix calculations.

The student failed to relate the numerical outcomes to the problem's context. Rather than explaining how the risk adjustment matrix affected the investment's value by comparing the investment before and after adjustment, the student provided a general statement about company management. Such a conclusion extends beyond the information provided in the problem and cannot be justified solely by the available mathematical evidence.

This finding indicates that the student had difficulty translating mathematical results into contextually valid conclusions. Instead of interpreting what the calculated values implied about the investment performance, the student introduced assumptions that were not represented in the mathematical model. Consequently, the interpretation did not accurately reflect the scope of the problem.

The findings suggest that students may obtain or recognize mathematical results yet still struggle to construct evidence-based interpretations. In contextual matrix problems, successful interpretation requires students to connect numerical results directly to the context represented by the matrices while avoiding conclusions that exceed the available evidence.

Interview findings suggested that many students viewed mathematics as a process of obtaining numerical answers rather than a tool for understanding real-world situations. Consequently, they rarely reflected on whether their answers were reasonable within the given context. This finding is consistent with previous studies indicating that students often experience difficulties in connecting mathematical solutions to contextual meanings (Irfan et al. 2022). Such difficulties demonstrate that contextual problem solving requires not only computational competence but also the ability to interpret and communicate mathematical results. The occurrence of interpretation errors highlights the need for instructional practices that encourage students to explain and justify their answers rather than merely perform calculations.

CONCLUSION

This study identified four major categories of errors made by undergraduate students when solving contextual matrix algebra problems: conceptual, mathematical modeling, procedural, and interpretation. The findings demonstrate that students' difficulties in solving contextual matrix algebra problems cannot be explained solely by computational deficits; they deeply involve conceptual understanding, mathematical modeling, procedural accuracy, and contextual interpretation. Mathematical modeling errors were the most prevalent, indicating significant hurdles in translating verbal information into appropriate matrix representations. These results highlight the critical importance of designing matrix algebra instruction that integrates authentic contextual problems with dedicated opportunities for students to develop mathematical modeling

and reasoning skills. Furthermore, the proposed four-category error classification provides a specific diagnostic framework for identifying students' learning difficulties in matrix algebra and serves as a foundation for developing targeted instructional strategies.

This study is subject to certain limitations. First, the qualitative descriptive design and the relatively small sample size, consisting of students from a single mathematics education program, may limit the generalizability of the findings. Second, the study focused specifically on contextual problems in a distinct subset of matrix algebra (matrix multiplication and investment contexts), meaning that students' error patterns might differ for other matrix topics, such as determinants or inverse matrices. Future research is recommended to involve larger and more demographically diverse student populations to validate and expand upon the identified error categories. Additionally, experimental or quasi-experimental studies should investigate the effectiveness of targeted instructional interventions, such as modeling-based scaffolding or contextual problem-based learning, based on this proposed error classification to actively improve students' mathematical modeling and problem-solving abilities in higher education settings.

ACKNOWLEDGMENTS

The authors would like to express their sincere gratitude to the expert validators who provided valuable feedback.

DECLARATIONS

Author Contribution : SMR: Conceptualization, Data Collection, Data Processing, Formal Analysis, Methodology; SN: Writing-Original Draft; N: Writing-Review, Editing; MMA: Writing-Review & Editing, Validation, and Supervision. All authors read and approved the final manuscript for publication.

Funding Statement : This research received no external funding.

Conflict of Interest : The authors declare no conflict of interest.

Additional Information : Additional information is available for this paper.

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