



CRITICAL THINKING IN MATRIX-BASED CRYPTOGRAPHY: INFORMING DEEP LEARNING ELECTRONIC MODULES FOR INCLUSIVE EDUCATION

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ABSTRACT

This study aims to analyze students' critical thinking skills in matrix topics within a cryptography context and to identify the need for developing a Deep Learning-based electronic module for inclusive classrooms. Employing a mixed-methods sequential explanatory design with a case study approach, the research began with a quantitative phase involving problem-solving tests administered to 10 eleventh-grade students in an inclusive class at SMA Muhammadiyah 3 Yogyakarta. The data were analyzed descriptively using Ennis's indicators, revealing low achievement in Reason, Clarity, and Overview, and moderate achievement in Focus and Inference. These findings indicate students' difficulties in identifying relevant information, constructing mathematical reasoning, drawing inferences, and systematically communicating encryption-decryption procedures. The qualitative phase was conducted to explain the underlying factors and explore instructional needs through interviews, observations, and a needs analysis survey, which were analyzed using thematic analysis and the Miles and Huberman model. The integration of both phases demonstrates that conventional instruction has not sufficiently addressed the cognitive needs of students in inclusive classrooms and that a Deep Learning-based electronic module incorporating step-by-step visualizations, matrix manipulation simulations, and conceptual scaffolding is urgently needed to systematically enhance students' critical thinking skills.

Keywords: Deep Learning; Critical Thinking Skills; Educational Cryptography; Inclusive Learning

Abstrak

Penelitian ini bertujuan untuk menganalisis keterampilan berpikir kritis siswa pada topik matriks dalam konteks kriptografi serta mengidentifikasi kebutuhan pengembangan modul elektronik berbasis *Deep Learning* untuk kelas inklusif. Dengan menggunakan desain metode campuran *sequential explanatory* dan pendekatan studi kasus, penelitian ini diawali dengan tahap kuantitatif yang melibatkan tes pemecahan masalah bagi 10 siswa kelas XI di kelas inklusif SMA Muhammadiyah 3 Yogyakarta. Data dianalisis secara deskriptif menggunakan indikator Ennis, yang menunjukkan capaian rendah pada aspek *Reason*, *Clarity* dan *Overview*, serta capaian sedang pada aspek *Focus* dan *Inference*. Temuan ini mengindikasikan adanya kesulitan siswa dalam mengidentifikasi informasi yang relevan, menyusun penalaran matematis, menarik kesimpulan, serta mengomunikasikan prosedur enkripsi-dekripsi secara sistematis. Tahap kualitatif dilakukan untuk menjelaskan faktor-faktor yang mendasari serta menggali kebutuhan pembelajaran melalui wawancara, observasi, dan survei analisis kebutuhan, yang kemudian dianalisis menggunakan analisis tematik dan model Miles & Huberman. Integrasi kedua tahap tersebut menunjukkan bahwa pembelajaran konvensional belum memadai dalam memenuhi kebutuhan kognitif siswa di kelas inklusif, sehingga modul elektronik berbasis *Deep Learning* yang memuat visualisasi langkah demi langkah, simulasi manipulasi matriks, dan scaffolding konseptual sangat diperlukan untuk meningkatkan keterampilan berpikir kritis siswa secara sistematis.

Kata Kunci: Deep Learning; Kemampuan Berpikir Kritis; Kriptografi Pendidikan; Pembelajaran Inklusif

1. INTRODUCTION

The development of education in the twenty-first century requires students to possess higher-order thinking skills, one of which is critical thinking. This ability enables students to analyze information, construct logical arguments, and make decisions based on strong evidence [1]. However, numerous studies indicate that Indonesian students' critical thinking skills remain relatively low, particularly in mathematics, a subject that demands precision and complex reasoning [2]. This low level of critical thinking is evident in students' difficulties in understanding abstract concepts, connecting prior knowledge, and solving non-routine problems. These conditions highlight the urgent need for innovative instructional approaches that can systematically and purposefully foster students' critical thinking skills.

Matrix topics constitute one area of mathematics that requires a high level of critical thinking, as they are closely related to various fields such as computation, economics, encryption, and mathematical modeling [3]. Despite their importance, many students experience difficulties in understanding fundamental matrix concepts, matrix operations, and their applications in real-world contexts. These challenges are more pronounced in inclusive classrooms, where students exhibit diverse academic abilities, learning styles, and special educational needs that must be accommodated by Hakim [4]. Without adaptive and contextual instructional approaches, the learning objectives of matrix topics are difficult to achieve optimally.

In the context of inclusive classrooms, teachers are required to provide differentiated instructional strategies that enable all students whether high, medium, or low-achieving to understand the material at their own pace [5]. However, classroom practices often reveal that mathematics instruction remains predominantly teacher-centered, one-directional, and limited in the use of interactive media that could support students' understanding of abstract concepts [6], [7]. As a result, students with special educational needs as well as those experiencing learning difficulties are less able to develop their critical thinking skills comprehensively. This situation reinforces the need for more adaptive and interactive learning media capable of bridging gaps in understanding.

One promising approach to fostering deep understanding and critical thinking is the Deep Learning approach, which emphasizes meaningful information processing so that students genuinely comprehend concepts rather than merely memorizing procedures [8]. This approach encourages students to engage in exploration, reflection, discussion, and repeated problem-solving, thereby making the learning process more meaningful. In matrix instruction, this approach can be integrated with a cryptography context, a field that utilizes matrix operations to secure digital data [9]. Such integration of real-world contexts is expected to enhance learning motivation and help students recognize the relevance of matrix concepts in everyday life.

The availability of electronic modules represents an important solution for supporting Deep Learning-based instruction, particularly in inclusive classrooms. Well-designed electronic modules enable interactive content delivery, incorporating animations, simulations, scaffolded exercises, and automated feedback to support independent learning [10], [11]. Moreover, electronic modules can enhance learning accessibility, as they can be used anytime and tailored to individual student needs. Nevertheless, electronic modules focusing on matrix topics that are specifically designed using a Deep Learning approach and a cryptography context, particularly those adapted to inclusive classroom settings, remain limited.

Based on the foregoing discussion, research on the analysis of students' critical thinking skills and the need for a Deep Learning-based electronic matrix module within a cryptography context in inclusive classrooms at SMA Muhammadiyah 3 Yogyakarta is highly relevant. This study is important for determining the current level of students' critical thinking skills and for identifying the actual need for innovative learning media that can effectively support inclusive learning processes.

2. LITERATURE REVIEW

2.1. Deep Learning

The Deep Learning approach in education emphasizes meaningful understanding rather than memorization. It encourages students to connect new knowledge with prior experiences, critically analyze information, and apply concepts to new and authentic contexts. Feriyanto [12] and Suryatama et al. [13] distinguish Deep Learning from surface learning by emphasizing students' intention to understand meaning and establish relationships among ideas. This perspective is supported by Biggs et al. [8], who argue that Deep Learning involves higher-order cognitive engagement, conceptual integration, and meaningful application of knowledge. Therefore, Deep Learning supports the development of critical thinking, problem-solving,

reflection, and knowledge transfer, making it highly relevant to student-centered education in the 21st century [14], [15].

The implementation of Deep Learning requires learning activities that actively involve students in inquiry, problem solving, collaboration, reflection, and authentic learning experiences. Project-based learning, problem-based learning, inquiry-based learning, and contextual learning can facilitate deeper engagement because students are encouraged to construct and apply knowledge rather than passively receive information [16]. Recent studies emphasize that Deep Learning can integrate meaningful, mindful, and joyful learning enabling students to develop conceptual understanding while maintaining active and positive engagement [17], [18]. Consequently, Deep Learning should be viewed not merely as a teaching method but as a comprehensive pedagogical approach that integrates cognitive, emotional, social, and reflective dimensions of learning to prepare students for complex real-world challenges [12].

2.2. Critical Thinking Skills

Critical thinking skills serve as a foundational pillar of modern education, empowering learners to analyze, evaluate, and synthesize information objectively rather than passively absorbing content. In an increasingly complex and media-saturated world, the capacity to identify logical fallacies, discern bias, and construct evidence-based arguments is crucial for academic success and informed citizenship [19]. Educational frameworks that prioritize these cognitive abilities shift the instructional focus from rote memorization toward inquiry-based learning, problem-solving, and reflective judgment [20]. By engaging in high-level cognitive tasks, students develop the intellectual autonomy necessary to navigate ambiguous scenarios and make reasoned decisions across diverse personal and professional contexts [21].

However, fostering robust critical thinking skills within standard educational curricula presents persistent pedagogical and institutional challenges. Traditional assessment methods often reward memorized facts and procedural compliance, making it difficult to measure abstract cognitive dimensions like critical reasoning and open-mindedness [22]. Furthermore, educators frequently struggle to balance dense subject-matter requirements with the time-intensive dialogue and scaffolding required to cultivate active questioning. To bridge this gap, contemporary instructional strategies are increasingly leveraging collaborative problem-solving, socratic seminar techniques, and digital simulation tools designed to stimulate deep reflective thinking and meta-cognitive awareness among student cohorts [23].

2.3. Educational Cryptography

Educational cryptography represents an innovative interdisciplinary domain that translates complex mathematical and cryptographic concepts into accessible pedagogical frameworks for students. As cybersecurity risks grow globally, there is an urgent societal need to build foundational knowledge regarding data privacy, encryption, and digital signatures from an early age [24]. By gamifying cryptographic principles such as using historical ciphers, visual cryptography, or puzzle-based challenges educators can effectively demystify abstract mathematical theories and foster computational thinking. This approach not only stimulates interest in Science, Technology, Engineering, and Mathematics (STEM) fields but also equips learners with the necessary digital hygiene and awareness to safely navigate modern internet infrastructure [25], [26].

Beyond teaching cybersecurity technicalities, educational cryptography serves as a powerful mechanism for enhancing general mathematical reasoning and algorithmic logic. When students manipulate cryptographic protocols, they engage directly with core algebraic concepts, modular arithmetic, and number theory in a tangible, goal-oriented setting [27]. The main challenge lies in designing curricula that balance conceptual rigor with cognitive accessibility, preventing students from becoming overwhelmed by dense notation or software implementation hurdles [28]. Recent literature emphasizes the development of interactive software tools, visual simulators, and collaborative peer-to-peer decoding activities that allow students to experiment with cryptographic algorithms safely and intuitively [29].

2.4. Inclusive Learning

Inclusive learning centers on the philosophical and pedagogical commitment to designing educational environments that cater to the diverse needs, backgrounds, and abilities of all students [30]. Moving away from a "one-size-fits-all" instruction model, inclusivity demands the proactive removal of systemic, physical, and cognitive barriers that marginalize learners with disabilities, varying socioeconomic statuses, or diverse linguistic backgrounds [31]. The implementation of frameworks like Universal Design for Learning (UDL) ensures that instructional materials, assessment strategies, and classroom interactions offer multiple means

of engagement and representation [32]. Consequently, inclusive classrooms foster a sense of belonging and equity, driving higher academic outcomes and emotional well-being for both marginalized groups and their peers.

Despite widespread institutional endorsement, realizing fully inclusive learning environments requires navigating complex systemic obstacles and deep-seated cultural resistances. Many educational systems suffer from underfunded resources, inadequate assistive technologies, and a shortage of specialized training programs necessary to prepare educators for highly diverse classrooms [33]. Furthermore, rigid standardized testing regimes often clash with the flexible, differentiated assessment methods required to fairly measure the progress of non-traditional learners. Addressing these systemic gaps requires a multi-layered approach, combining sustained professional development for teachers, institutional policy reforms, and the strategic integration of accessible educational technologies that empower every learner to succeed [34].

3. METHOD

This study employed a mixed-methods sequential explanatory design combined with a case study approach, beginning with a quantitative phase followed by a qualitative phase to provide an in-depth understanding of students' critical thinking skills and the learning needs related to Deep Learning-based matrix instruction within a cryptography context. In the quantitative phase, data were collected through problem-solving ability tests administered to students in inclusive classrooms, specifically 10 eleventh-grade students with special educational needs at SMA Muhammadiyah 3 Yogyakarta. The data were analyzed descriptively using percentage-based achievement of indicators. The quantitative results were then visualized in the form of achievement tables to reveal the levels of students' critical thinking skills as well as specific weaknesses in each critical thinking indicator [35].

The qualitative phase was conducted after the quantitative results had been analyzed and aimed to explain the factors contributing to students' low problem-solving abilities and to explore learning needs from both teachers' and students' perspectives. Data were collected through in-depth interviews, classroom observations, and a needs analysis survey, with mathematics teachers and students serving as the primary informants. Qualitative data analysis employed thematic analysis following Braun and Clarke's framework and the interactive model of Miles & Huberman [36], which includes data reduction, data display, and conclusion drawing, and was strengthened through source and method triangulation. The integration of the two phases provides a comprehensive depiction of students' critical thinking abilities and the need for developing Deep Learning-based matrix instructional materials for inclusive classrooms.

4. RESULTS

4.1. Quantitative Phase

Based on the results of a critical thinking skills test compiled using indicators according to Ennis [37], namely Focus, Reason, Inference, Situation, Clarity, and Overview, students were given six contextual descriptive questions that linked the concept of matrices to the activities of encrypting and decrypting messages in cryptography. This test aims to assess the extent to which students are able to analyze information, reason, draw conclusions, understand the context of the problem, and reflect on the results of their thinking.

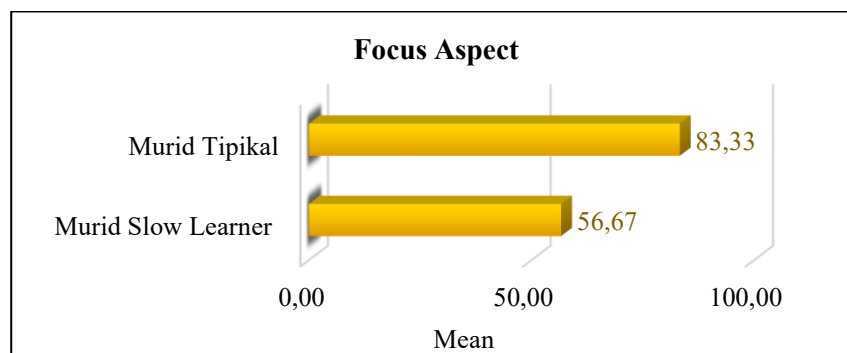


Figure 1. Results of Students' Critical Thinking Ability Test, Focus Aspect

In the Focus aspect, typical students achieved the highest score of 83.33, while slow learners achieved 56.67. This data confirms that typical students are better able to work systematically, focus on goals, and complete tasks without deviation. Slow learners tend to struggle to maintain focus, especially when faced with multi-

level assignments. Therefore, Deep Learning-based electronic modules in the context of cryptography need to be equipped with simple navigation features, clear stages, and level-based gamification to maintain student attention and increase learning motivation. With an adaptive, interactive, and contextual learning design, critical thinking skills in inclusive classes can develop more evenly and sustainably.

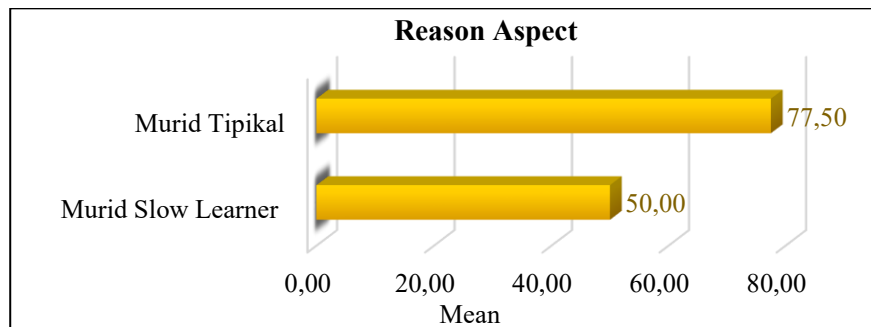


Figure 2. Results of Students' Critical Thinking Ability Test, Reason Aspect

In the reasoning aspect, typical students showed a high score of 77.50, while slow learners only scored 50.00. This difference indicates that typical students have a stronger tendency to think analytically in connecting cause and effect, while slow learners tend to make decisions without in-depth reasoning. Thus, cryptography-based mathematics learning can be a powerful medium for building reasoning skills through the exploration of codes, matrix transformations, and code-breaking logic. The designed electronic module should provide step-by-step reasoning features, error feedback, and logic puzzle-based exercises to train argument justification gradually and consistently.

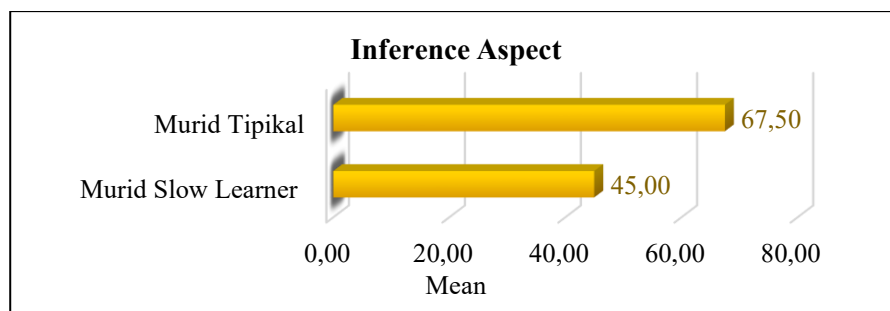


Figure 3. Results of Students' Critical Thinking Ability Test for Inference Aspect

In the inference aspect, typical students scored 67.50, while slow learners scored 45.00. This gap indicates that typical students are better able to identify patterns, predict outcomes, and make logical decisions, while slow learners need support in building relationships between data. Slow learners' low inference ability indicates that their thinking processes are not yet fully structured and are still at the knowledge recall stage. Deep Learning-based electronic modules in the context of cryptography can provide step-by-step inference practice, predicting encryption patterns, or re-arranging encrypted data, so that the ability to connect data and draw conclusions can develop more naturally.

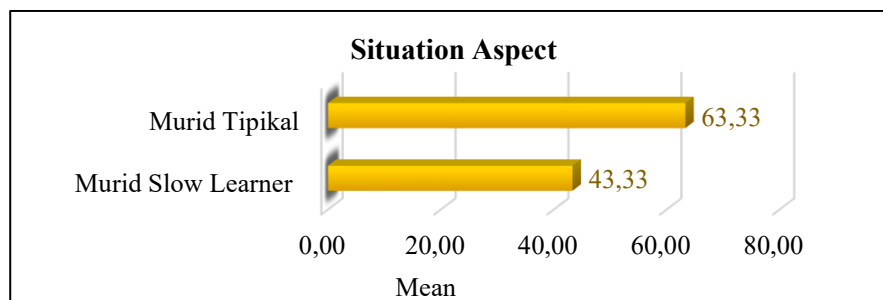


Figure 4. Results of Students' Critical Thinking Ability Test for the Situation Aspect

In the situation aspect, typical students scored 63.33, while slow learners only achieved 43.33. This indicates that typical students are better able to place problems in logical situations and interpret relationships between information. In the context of inclusive learning, slow learners need support in the form of real-life examples and problem-based learning experiences to understand the relevance of the material to real life. Cryptography as a learning context has great potential because it presents mathematical applications in digital data security issues that are close to modern life. Deep Learning-based electronic modules can provide simulations of cipher keys and simple matrix patterns so that students' situational understanding increases gradually and meaningfully.

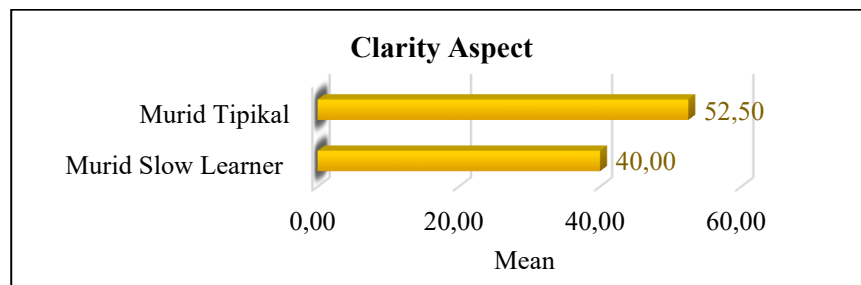


Figure 5. Results of Students' Critical Thinking Ability Test in Clarity Aspect

In terms of clarity, typical students scored 52.50, while slow learners scored 40.00. This difference indicates that typical students are better able to interpret complex information and organize it into a logical structure, while slow learners require time and assistance to decipher the meaning of the problem. This lack of clarity leads to reasoning errors in subsequent stages. Therefore, electronic modules based on the Deep Learning approach need to include features such as guided questions, nested examples, and the use of simple cryptography as a practice context to make the problem clarification process more focused and meaningful.

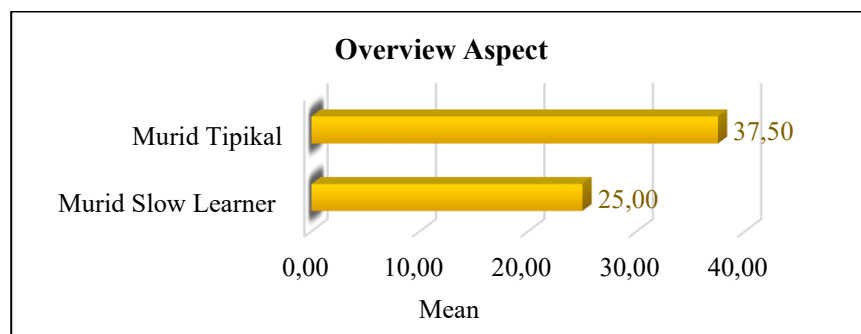


Figure 6. Results of Students' Critical Thinking Ability Test Overview Aspect

In the overview aspect, typical students scored an average of 37.50, while slow learners only scored 25.00. This score indicates that in the initial stages of critical thinking, typical students are better able to recognize the problem context, connect initial information, and identify the purpose of the question. Conversely, slow learners tend to have difficulty understanding the problem structure before moving on to the solution steps. This condition demonstrates the importance of providing step-by-step instructions, contextual examples, and problem visualizations so that slow learners can achieve an equivalent initial understanding. This underpins the need for Deep Learning-based electronic modules to facilitate more efficient initial understanding.

4.2. Qualitative Phase

Based on the results of a critical thinking skills test developed using [1] indicators, including Focus, Reason, Inference, Situation, Clarity, and Overview, students completed six contextual essay questions connecting matrix material to the encryption and decryption processes of messages in cryptography. The percentage of achievement from this test is presented as follows.

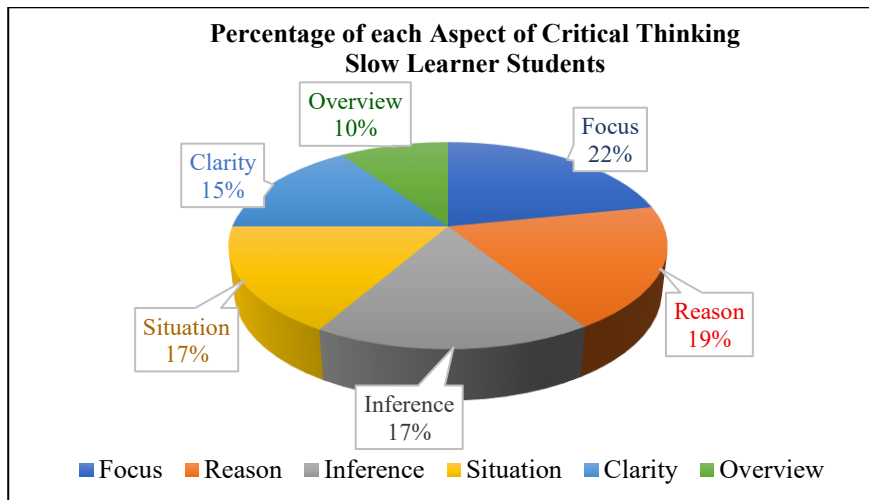


Figure 7. Percentage of each Aspect of Critical Thinking of Slow Learners

The results of the study show that students' critical thinking skills are slow learners, with achievements in Focus (22%), Reason (19%), Inference (17%), Situation (17%), Clarity (15%), and Overview (10%). These findings provide a comprehensive overview of students' thought processes in understanding the matrix concept used in message encryption and decryption, as well as revealing various cognitive obstacles that arise during the learning process. The first aspect is Focus, which has the highest percentage of 22%. identifying the core of the problem and sorting important information from additional information when facing questions. The following is an excerpt from the results of M1 No. 1 answers.

Informasi penting: Mendeskripsikan pesan ubah ke asli
 Kunci = $\begin{bmatrix} 3 & 3 \\ 2 & 5 \end{bmatrix}$, $K = \frac{1}{9} \begin{bmatrix} -3 & 2 \\ 3 & -5 \end{bmatrix}$, $A = \frac{1}{9} \begin{bmatrix} 5 & -3 \\ -2 & 3 \end{bmatrix}$

Figure 8. Answer M1 No.1

Based on Figure 8, the student has not yet fully written additional information and has not been able to select important information in the question. The following is an excerpt from the interview.

- P : Have you read the problem carefully to ensure you understand its purpose?"
 M1 : Yes, ma'am, I have read the problem, even several times.
 P : So, what information do you know and what is being asked in the problem?
 M1 : Regarding the important information in describing the message of the problem, there is a key matrix, matrix A, matrix K, and you are asked to convert it back into letter form.
 P : If so, why didn't you include the information you already know and the question asked on the answer sheet?
 M1 : That's enough, ma'am.

These findings indicate that despite being slow learners, students actually have quite good potential for maintaining attention and following the flow of problem-solving when instructions are given clearly and structured. However, this ability to focus is not yet fully integrated with other critical thinking skills, such as reasoning and inference, so their work sometimes appears to be simply following steps without understanding the conceptual meaning of the process. This condition indicates that learning needs to be designed using a gradual approach so that students' focus can become a capital for developing higher-level logical and cognitive understanding. The second specification, Reason, with a percentage of 19%, indicates that the ability to provide reasons, justification, or logic in problem-solving is still at a moderate level. The following is an excerpt from the results of M1 No. 4.

$$\begin{aligned} \begin{bmatrix} 57 \\ 10 \end{bmatrix} &\rightarrow \frac{1}{9} \begin{bmatrix} 5 & -3 \\ -2 & 3 \end{bmatrix} \begin{bmatrix} 57 \\ 10 \end{bmatrix} = \begin{bmatrix} 15 \\ 49 \end{bmatrix} \\ \begin{bmatrix} 33 \\ 22 \end{bmatrix} &\rightarrow \frac{1}{9} \begin{bmatrix} 5 & -3 \\ -2 & 3 \end{bmatrix} \begin{bmatrix} 33 \\ 22 \end{bmatrix} = \begin{bmatrix} 11 \\ 0 \end{bmatrix} \\ \begin{bmatrix} 27 \\ 18 \end{bmatrix} &\rightarrow \frac{1}{9} \begin{bmatrix} 5 & -3 \\ -2 & 3 \end{bmatrix} \begin{bmatrix} 27 \\ 18 \end{bmatrix} = \begin{bmatrix} 9 \\ 0 \end{bmatrix} \\ \begin{bmatrix} 129 \\ 164 \end{bmatrix} &\rightarrow \frac{1}{9} \begin{bmatrix} 5 & -3 \\ -2 & 3 \end{bmatrix} \begin{bmatrix} 129 \\ 164 \end{bmatrix} = \begin{bmatrix} 13 \\ 26 \end{bmatrix} \\ \begin{bmatrix} 69 \\ 88 \end{bmatrix} &\rightarrow \frac{1}{9} \begin{bmatrix} 5 & -3 \\ -2 & 3 \end{bmatrix} \begin{bmatrix} 69 \\ 88 \end{bmatrix} = \begin{bmatrix} 9 \\ 19 \end{bmatrix} \\ \begin{bmatrix} 45 \\ 57 \end{bmatrix} &\rightarrow \frac{1}{9} \begin{bmatrix} 5 & -3 \\ -2 & 3 \end{bmatrix} \begin{bmatrix} 45 \\ 57 \end{bmatrix} = \begin{bmatrix} 6 \\ 9 \end{bmatrix} \end{aligned}$$

Figure 9. Answer M1 No. 4

Based on Figure 9, it can be seen that student M1 has worked on the problem but has not finished compiling it. The following are the results of the interview.

- P : What considerations did you use to answer the question?
 M1 : I wrote my answer based on the information in the question, in a coherent manner.
 P : Do you think the reasoning you provided is correct?
 M1 : I think so, ma'am, but I haven't finished calculating everything yet.

Slow learners can generally answer questions if they have a pattern or previous example, but often struggle when asked to explain the reasoning behind their answers. This indicates that their reasoning is still mechanical rather than analytical. Therefore, using learning contexts such as cryptography can help improve their reasoning skills because they are logical and pattern-based. With the support of Deep Learning-based electronic modules, students can be given tiered exercises that encourage them not only to find answers but also to explain their thinking. The third aspect is Inference, which also accounts for 17%. This aspect demonstrates students' ability to draw conclusions based on available information. This percentage indicates that slow learners are beginning to make connections between data, although their reasoning is not yet fully accurate or in-depth. The following is an excerpt from the results of M1 No. 6.

Dapat dikerjakan dengan matriks

Figure 10. Answer M1 No.6

Based on Figure 10, M1 wrote an incomplete reason. The following is a transcript of the interview results related to M1's work.

- P : What do you understand more about this problem?
 M1 : Provides experience in solving problems using matrices.
 P : Is that all?
 M1 : Same for breaking down codes into letter forms.

Their greatest difficulty lies in distinguishing relevant from irrelevant information and interpreting hidden patterns within a problem. In the context of learning development, e-modules utilizing Deep Learning strategies are highly appropriate because they can present real-life examples, interactive simulations, and cryptography-based decoding exercises, helping students establish logical relationships between data before drawing conclusions. The fourth aspect, Situation, also scored 17%, indicating that slow learners are quite capable of placing information in a specific context, especially when supported by visuals, concrete examples, or direct learning experiences. The following is an excerpt from the answers from M1 No. 2.

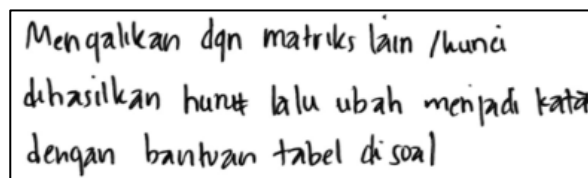
Menghitung invers matriks, lalu menyusun
kalimat utuh lalu ubah menjadi huruf
konotas

Figure 11. Answer M1 No.2

Based on the image above, M1 is quite capable of understanding the context of the problem in the question. Here are the results of the interview.

- P : Before you begin calculating, can you explain the context of the given cryptographic problem? The matrix containing the initial message will be operated on with the key matrix to produce an encrypted message.
- M1 : So, what important information should you identify first?
- P : The order of operations, since encryption and decryption use different methods.
- M1 : So, do you understand the relationship between matrix operations and the context of the problem?
- P : Yes, ma'am, because the problem involves converting numbers to letters.
- M1 : Before you begin calculating, can you explain the context of the given cryptographic problem? The matrix containing the initial message will be operated on with the key matrix to produce an encrypted message.

The use of a secure message context motivates students and enables them to follow the situational narrative. They can understand the storyline, for example, the process of converting a text message into a number or multiplying by a key matrix. However, observations show that understanding the context is not yet accompanied by strong analytical skills. A learning approach that utilizes a cryptographic context will help slow learners understand that mathematical concepts are not just theoretical but also useful in the real world. Thus, the Situational aspect can be improved if the learning media is contextual, applicable, and experience-based. The fifth aspect, Clarity, with a percentage of 15%, indicates that the ability to clarify instructions, understand the meaning of the problem, and convey understanding coherently is still relatively low. The following is an excerpt from the answers to M1 No. 3.



Gambar 1. M1 No.3

Based on the image above, the student has re-explained the activities or steps for solving the problem, but it is not coherent and with limited communication. The following are the interview results.

- P : Explain in your own words what you're calculating in this step.
- M1 : That's... I'm just multiplying the matrices and then converting the numerical data to letters.
- P : So, can you explain how this result is used in the message encryption or decryption process?
- M1 : That's it, ma'am. I don't really understand. Basically, after multiplying, it becomes a new code. I can't explain it in more detail yet.

Slow learners often experience confusion when trying to translate complex information into simple structures of understanding. This deficiency results in errors in subsequent stages, such as inference and reasoning. Therefore, e-modules require information simplification features such as highlighting, voice support, visual step-by-step examples, and guiding questions to help students process the information they receive before moving on to higher-level thinking. The final aspect, Overview, had the lowest percentage, at 10%. This indicates that slow learners still face significant challenges in understanding the overall picture of a problem before beginning to solve it. The following is an excerpt from the answers to M1 No. 5.

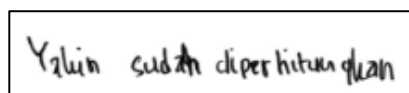


Figure 13. M1 No.5

Based on the image above, M1 is unable to reevaluate the problem-solving process he is working on. The following is the result of his interview.

- P : Are you sure about your answer? Explain why.
- M1 : I'm sure, ma'am, because I followed the formula.
- P : Do you know of any other method to double-check your answer?
- M1 : No, ma'am, that's all.

They tend to immediately try to answer without understanding the main context, problem structure, or learning objectives. This situation indicates the need for early learning interventions that focus on material orientation, the use of analogies, and a gradual introduction to context before moving on to problem solving. By utilizing Deep Learning in e-modules, students can experience iterative, tiered, and reinforced learning through visualization and simulation, allowing their ability to understand the general picture to develop more systematically and sustainably.

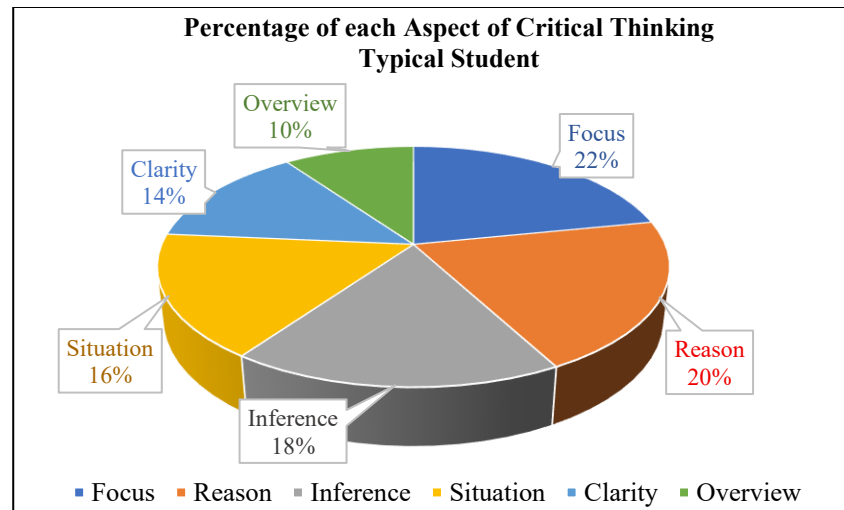


Figure 14. Percentage of each Aspect of Critical Thinking of Typical Students

The results of the study show that the critical thinking skills of slow learner students, with achievements of Focus (22%), Reason (20%), Inference (18%), Situation (16%), Clarity (14%), and Overview (10%). These findings provide a comprehensive picture of the students' thinking process in understanding the concept of matrices used in message encryption and decryption, as well as revealing various cognitive obstacles that arise during the learning process. The first aspect, namely Focus, which has the highest percentage of 22%, shows that typical students have good abilities in maintaining attention and completing tasks systematically. The following is an excerpt from the results of M2 No. 1's answers.

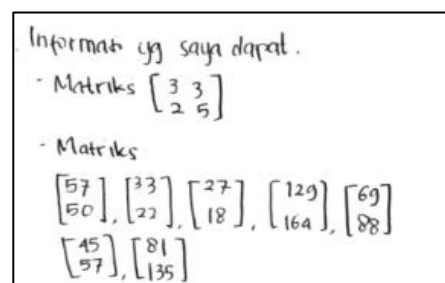


Figure 15. Answer M2 No. 1

Based on the image, the student has not yet fully written down additional information and has not been able to select important information in the question. The following is an excerpt from the interview.

- P : Have you read this question carefully to ensure you understand what is being asked?
- M2 : I've read it several times to fully understand it.
- P : Okay. From this question, what important information do you already know, and what are you being asked to do?
- M2 : This question asks me to describe a message using several matrices: the key matrix, the A matrix, and the K matrix. The task is to convert the results back into letter form.
- P : So, why aren't the information you already know and the question in this question listed on the answer sheet?
- M2 : Actually, I have, ma'am.

Typical students are able to follow instructions, maintain a consistent train of thought, and complete problem-solving steps without being easily distracted. This indicates they have mastered basic concentration skills,

enabling more effective learning, especially in abstract mathematical topics such as matrix cryptography. This ability to focus is an important foundation for critical thinking because it allows students to process information deeply and consistently until they reach a logical and correct solution. The second aspect, Reason, with a score of 20%, indicates that typical students are already at a good level of logical thinking, able to provide reasons and justification for solving problems. The following is an excerpt from the results of M2 No. 4.

Invers matriksnya = $\frac{1}{9} \begin{bmatrix} 5 & -3 \\ -2 & 3 \end{bmatrix}$

Hasil kali nya :

$$\begin{bmatrix} 57 \\ 50 \end{bmatrix} \rightarrow \frac{1}{9} \begin{bmatrix} 5 & -3 \\ -2 & 3 \end{bmatrix} \cdot \begin{bmatrix} 57 \\ 50 \end{bmatrix} = \frac{1}{9} \begin{bmatrix} 135 \\ 36 \end{bmatrix} = \begin{bmatrix} 15 \\ 4 \end{bmatrix}$$

$$\begin{bmatrix} 33 \\ 22 \end{bmatrix} \rightarrow \frac{1}{9} \begin{bmatrix} 5 & -3 \\ -2 & 3 \end{bmatrix} \cdot \begin{bmatrix} 33 \\ 22 \end{bmatrix} = \frac{1}{9} \begin{bmatrix} 99 \\ 0 \end{bmatrix} = \begin{bmatrix} 11 \\ 0 \end{bmatrix}$$

$$\begin{bmatrix} 27 \\ 18 \end{bmatrix} \rightarrow \frac{1}{9} \begin{bmatrix} 5 & -3 \\ -2 & 3 \end{bmatrix} \cdot \begin{bmatrix} 27 \\ 18 \end{bmatrix} = \frac{1}{9} \begin{bmatrix} 81 \\ 0 \end{bmatrix} = \begin{bmatrix} 9 \\ 0 \end{bmatrix}$$

$$\begin{bmatrix} 129 \\ 164 \end{bmatrix} \rightarrow \frac{1}{9} \begin{bmatrix} 5 & -3 \\ -2 & 3 \end{bmatrix} \cdot \begin{bmatrix} 129 \\ 164 \end{bmatrix} = \frac{1}{9} \begin{bmatrix} 153 \\ 234 \end{bmatrix} = \begin{bmatrix} 17 \\ 26 \end{bmatrix}$$

$$\begin{bmatrix} 69 \\ 88 \end{bmatrix} \rightarrow \frac{1}{9} \begin{bmatrix} 5 & -3 \\ -2 & 3 \end{bmatrix} \cdot \begin{bmatrix} 69 \\ 88 \end{bmatrix} = \frac{1}{9} \begin{bmatrix} 61 \\ 126 \end{bmatrix} = \begin{bmatrix} 7 \\ 14 \end{bmatrix}$$

$$\begin{bmatrix} 45 \\ 57 \end{bmatrix} \rightarrow \frac{1}{9} \begin{bmatrix} 5 & -3 \\ -2 & 3 \end{bmatrix} \cdot \begin{bmatrix} 45 \\ 57 \end{bmatrix} = \frac{1}{9} \begin{bmatrix} 54 \\ 81 \end{bmatrix} = \begin{bmatrix} 6 \\ 9 \end{bmatrix}$$

$$\begin{bmatrix} 81 \\ 135 \end{bmatrix} \rightarrow \frac{1}{9} \begin{bmatrix} 5 & -3 \\ -2 & 3 \end{bmatrix} \cdot \begin{bmatrix} 81 \\ 135 \end{bmatrix} = \frac{1}{9} \begin{bmatrix} 0 \\ 243 \end{bmatrix} = \begin{bmatrix} 0 \\ 27 \end{bmatrix}$$

Jadi $\begin{bmatrix} 15 & 11 & 17 & 9 & 6 & 0 & 27 & 27 \\ 4 & 0 & 26 & 14 & 7 & 14 & 9 & 4 \end{bmatrix}$

$\begin{bmatrix} P & L & J & E \\ 4 & 4 & 2 & 0 \end{bmatrix}$

Figure 16. Answer M2 No. 4

Based on Figure 4, it can be seen that student M2 has worked on the problem but has not finished compiling it. The following are the results of the interview.

- P : What did you consider when answering this question?
- M2 : I tried to write my answer based on the information in the question and complete it sequentially.
- P : Do you think it's correct?
- M2 : Yes, ma'am.

A typical student not only follows the steps to solve a problem but can also explain the relationship between the process and the result. In the context of learning matrix cryptography, students are able to understand why certain steps are necessary, for example when calculating determinants, using matrix inverses, or applying number transformation operations to code. This percentage demonstrates the continued development of mature reasoning skills and indicates that a typical student is ready to enter a challenging level of learning based on mathematical logic and real-world problem solving.

The third aspect, Inference, with a percentage of 18%, illustrates students' ability to draw conclusions from presented data. The following is an excerpt from the results of M2 No. 6.

Sandi dapat dipecahkan dengan belajar matriks

Figure 17. Answer M2 No. 6

Based on Figure 17, M2 wrote an incomplete reason. The following is a transcript of the interview results related to M2's work.

- P : What do you understand more about this matter?
- M2 : This problem gave me experience in solving problems using matrices in a crypto context
- P : Is that all?
- M2 : No, also to change the password to letter form.

Typical students demonstrate proficiency in connecting information, recognizing patterns, and making predictions based on available mathematical data. For example, they can understand that changing values in a matrix will affect the encryption or decryption of a message. This inference ability demonstrates the

development of analytical thinking that relies not only on instructions but also on the ability to process information to generate new understanding. In the context of Deep Learning-based learning, this ability is crucial because it is directly related to the formation of reflective and applicable thought structures. The fourth aspect, Situation, with a percentage of 16%, indicates that typical students have a fairly good ability to understand the context of a problem. The following is an excerpt from the results of M2 No. 2.

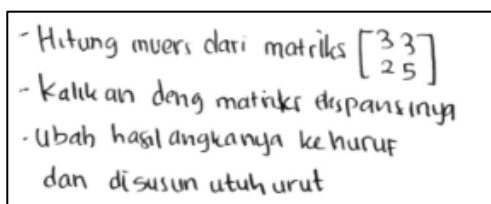


Figure 18. Answer M2 No. 2

Based on the image in 18, M2 is able to understand the context of the problem in the question. The following are the results of the interview.

- P : Before calculating, could you explain the context of this cryptography problem?
 M2 : The initial message matrix will be multiplied by the key matrix to produce the encrypted message.
 P : What important information needs to be identified first?
 M2 : The order of operations, since encryption and decryption are different.
 P : So, do you understand the relationship between matrix operations and the problem?
 M2 : Yes, ma'am, because the goal is to convert numbers to letters.

A typical student can relate mathematical concepts to their application in cryptography, making the learning process more than just procedural but also meaningful. This situational ability helps students understand the relevance of using matrices in data security systems, message encryption, and information technology applications. Although not as high as other aspects, this ability demonstrates students' readiness for contextual, project-based learning and real-world simulations. The fifth aspect, Clarity, with a percentage of 14%, reflects students' ability to clarify information, organize ideas coherently, and convey understanding clearly. The following is an excerpt from the results of M2 No. 3.

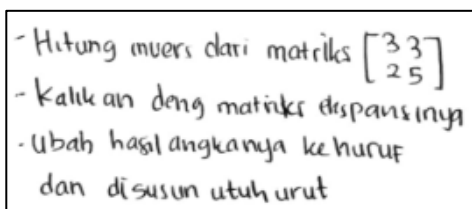


Figure 19. Answer M2 No. 3

Based on Figure 19, M2 has re-explained the activities or steps for solving the problem with limited communication. The following are the results of the interview.

- P : What are you calculating in this step? Explain!
 M2 : I multiply the encryption matrix by the inverse of the key matrix. The result is a number that I convert to letters using a conversion table.
 P : How is this result used in the process of encrypting or decrypting a message?
 M2 : From the table of numbers converted to letters, I rewrite them to form a complete word, ma'am.

Although lower than other aspects, typical students still tend to understand instructions well, but sometimes struggle to organize mathematical language into concise and accurate verbal explanations. This indicates that learning needs to support mathematical communication skills through written reflection exercises, group discussions, or presentations of problem-solving processes so students can develop clarity of thought and convey ideas. The final aspect, Overview, which had the lowest percentage at 10%, indicates that students still need reinforcement in understanding the full picture of the problem before beginning to solve it. The following is an excerpt from the results of M2 No. 5.

Yakin, karena sudah dihitung lagi

Figure 20. Answer M2 No. 5

Based on Figure 20, M2 was unable to re-evaluate the problem-solving process he was working on. The following are the results of his interview

- P : Are you sure about your answer? Why?
 M2 : Yes, ma'am, because I followed the flow of the question.
 P : Is there another way to check your answer?
 M2 : No, ma'am, that's the only way.

Although they are able to solve problems, some students are not accustomed to starting with initial analysis, such as the problem's objective, the relationships between variables, or the information structure. This percentage emphasizes the importance of beginning learning with problem framing, advanced organizers, and conceptual orientation steps to provide students with a strong foundation of initial understanding. With a step-by-step approach and digital learning support, these overview skills can develop, so that problem-solving is not simply a matter of following steps but based on a comprehensive understanding. A questionnaire survey of students at SMA Muhammadiyah 3 Yogyakarta showed that most students found it difficult to understand the matrix material due to the lack of media connecting theory with real-world applications. Based on preliminary interviews with teachers, it was discovered that learning still relies on lectures and routine exercises from textbooks. This reduces students' opportunities to explore ideas, discuss, or relate the material to their daily lives.

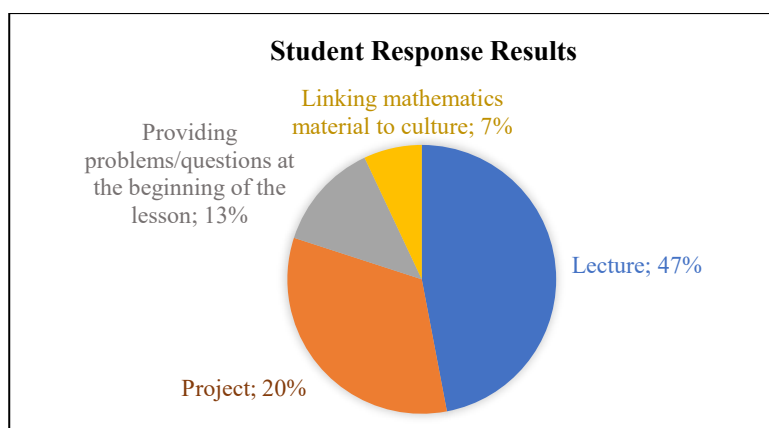


Figure 21. Results of Student Responses to the Learning Process

Based on the diagram above, it can be seen that the lecture method still dominates learning, with a percentage of 47%, indicating that most teachers still use a traditional teacher-centered approach. Meanwhile, the project method is used by 33% of teachers, indicating an effort to engage students in more applicable and collaborative activities. Only 13% of teachers begin learning by providing contextual problems or questions, and 7% link mathematical material to local cultural elements. These data indicate that learning approaches that foster critical and contextual thinking skills are still limited. Therefore, more interactive learning innovations are needed, such as the development of Deep Learning-based electronic modules with a cryptographic context, so that students can be more active, creative, and able to connect mathematical concepts to real life and cultural values.

5. Discussion

Based on the quantitative findings, students' critical thinking skills particularly between typical students and slow learners exhibited significant differences across all Ennis [37] aspects, namely Focus, Reason, Inference, Situation, Clarity, and Overview. In the Focus aspect, typical students achieved the highest score (83.33), whereas slow learners attained only 56.67. This result indicates that typical students are better able to maintain attention, work systematically, and complete tasks with minimal deviation, while slow learners require clearer guidance and more structured, step-by-step learning to sustain focus. These findings are consistent with previous studies emphasizing that focus is a fundamental component of critical thinking, as unstable attention undermines effective information analysis and decision-making processes. In this context,

the development of Deep Learning-based electronic modules with simple navigation, clearly defined stages, and gamification elements represents a potential solution to enhance engagement and learning motivation among slow learners.

The Reason aspect also revealed a marked disparity, with typical students scoring 77.50 and slow learners scoring 50.00. Typical students demonstrated the ability to provide logical and analytical justifications in problem-solving, whereas slow learners tended to follow patterns or procedural steps without a deep understanding of causal relationships. Interview data supported this finding, showing that slow learners often struggled to explain the rationale behind their answers despite being able to follow instructions. Previous research highlights the importance of learning contexts that stimulate reasoning, such as cryptography-based problems that require code analysis, matrix transformations, and numerical logic. Through electronic modules equipped with step-by-step reasoning exercises and interactive feedback, students can be gradually trained to think more critically and to construct mathematical justifications in a structured manner [38].

The Inference aspect, with scores of 67.50 for typical students and 45.00 for slow learners, reflects students' abilities to draw conclusions and identify patterns from available data. This gap indicates that typical students are more proficient in connecting information and making logical predictions, whereas slow learners still rely heavily on knowledge recall rather than deep conceptual understanding. Interview findings revealed that slow learners experienced difficulties in distinguishing relevant from irrelevant information. Prior studies suggest that interactive simulations and cryptography-based decoding exercises can effectively support the development of inference skills by making causal relationships more explicit. Deep Learning-based modules enable students to experience the inference process progressively through contextualized and repeated learning experiences, thereby significantly enhancing their ability to integrate data and derive conclusions.

The Situation aspect, which assesses the ability to contextualize problems, showed scores of 63.33 for typical students and 43.33 for slow learners. Typical students were able to recognize the relevance of mathematical content to real-world situations, whereas slow learners required concrete examples and problem-based learning experiences to grasp contextual meaning. Interview results indicated that although slow learners understood the procedural sequence of encryption and decryption operations, they had not yet fully connected matrix concepts to real-life applications. Previous research emphasizes that applied contexts, such as digital message encryption, can enhance motivation and situational understanding. Electronic modules incorporating key visualizations and interactive simulations allow students to engage in realistic learning experiences, thereby fostering meaningful development of situational understanding.

The Clarity and Overview aspects yielded the lowest scores, with Clarity at 52.50 (typical students) and 40.00 (slow learners), and Overview at 37.50 (typical students) versus 25.00 (slow learners). Typical students were better able to interpret complex information but still required support to articulate their understanding coherently, while slow learners struggled to decompose information and to grasp the overall structure of problems. These findings align with previous research emphasizing the importance of advance organizers, guided questioning, and scaffolding in inclusive learning environments to help students establish an initial conceptual framework before processing more complex information [39]. Through a Deep Learning approach, electronic modules can provide progressive visualizations, contextual examples, and reflective exercises, thereby systematically enhancing students' clarification and overview skills.

The findings of this study are consistent with previous research indicating that the integration of cryptography contexts into mathematics learning can enhance students' initial understanding and learning motivation; however, it does not automatically foster higher-order reasoning and inference skills without meaningful instructional support [24], [40]. Deep Learning-based instruction on matrix topics has also been shown to improve students' analytical and reasoning abilities when learners are provided with repeated opportunities for exploration, reflection, and problem-solving [22], [41]. Moreover, students in inclusive classrooms benefit from explicit scaffolding, visual representations, and structured guidance to strengthen their clarity of thinking and reasoning processes [42], [43]. The consistency between the present findings and previous studies highlights the urgent need to develop Deep Learning-based electronic modules within a cryptography context as adaptive, constructive, and inclusive learning media that effectively support the development of students' critical thinking skills [44].

Overall, this study confirms that students' critical thinking skills particularly those of slow learners require further support through interactive, contextual, and adaptive instructional strategies. The Focus and Reason aspects represent initial strengths that can be enhanced through gradual practice, while the Inference,

Situation, Clarity, and Overview aspects require targeted interventions in the form of authentic learning experiences, simulations, and consistent feedback. The use of Deep Learning-based electronic modules within a cryptography context is therefore highly relevant for fostering comprehensive critical thinking skills, in line with previous research demonstrating that interactive media can enhance conceptual understanding, learning motivation, and problem-solving skills in inclusive classrooms. Consequently, this approach not only supports students in mastering abstract mathematical concepts but also prepares them to think analytically and reflectively in addressing real-world challenges.

6. CONCLUSION

The findings of this study indicate that students' critical thinking skills in matrix topics within a cryptography context remain at a low level, particularly in the Reason, Clarity, and Overview indicators, as well as partially in Focus and Inference, in both regular and inclusive classrooms at SMA Muhammadiyah 3 Yogyakarta. Although the Situation indicator was classified as high, this result merely reflects students' ability to comprehend the narrative context without being accompanied by adequate conceptual analysis. The qualitative findings reinforce the quantitative results, revealing that students experience difficulties in identifying core information, constructing mathematical reasoning, drawing inferences, and coherently communicating the encryption–decryption process, largely due to the dominance of conventional, teacher-centered instructional practices.

The consistency of these findings with previous studies underscores the need for a new instructional intervention through the development of a Deep Learning–based electronic module within a cryptography context that provides step-by-step visualizations, matrix manipulation simulations, representational scaffolding, predictive exercises, and reflective activities. Therefore, the development of a Deep Learning–based electronic matrix module within a cryptography context is strongly required to enhance students' critical thinking skills in inclusive classrooms at SMA Muhammadiyah 3 Yogyakarta.

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