

Characteristics of Students' Cognitive Load in Mathematics Learning

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Abstract

Abstract (English)

This study aims to describe the characteristics of students' cognitive load in mathematics learning, particularly in the topic of Gauss–Jordan elimination, and to identify the factors influencing intrinsic cognitive load, extraneous cognitive load, and germane cognitive load. This research employed a descriptive qualitative approach conducted with students of the Informatics Technology Study Program who were enrolled in a linear algebra course. The research subjects consisted of 15 students selected using purposive sampling. Data were collected through classroom observations, a cognitive load questionnaire, and in-depth interviews. The data were analyzed using the Miles and Huberman model, which includes data reduction, data display, and conclusion drawing. The results indicate that students' intrinsic cognitive load was categorized as high, with 72% of students experiencing difficulties in understanding concepts, requiring substantial mental effort, and needing considerable time to determine solution steps. Extraneous cognitive load was categorized as moderate, with 46% of students showing difficulties related to the presentation of materials and symbolic representations. Meanwhile, germane cognitive load was categorized as high, with 74% of students demonstrating active efforts to understand concepts, applying systematic strategies, and reflecting on their problem-solving processes. These findings suggest that although students experienced a high level of intrinsic cognitive load, they were still able to construct conceptual understanding through active engagement in learning. This study implies that structured and systematic instructional design can help manage students' cognitive load and enhance the effectiveness of mathematics learning in higher education.

Abstrak (Indonesia)

Penelitian ini bertujuan untuk mendeskripsikan karakteristik beban kognitif mahasiswa dalam pembelajaran matematika, khususnya pada materi eliminasi Gauss–Jordan, serta mengidentifikasi faktor-faktor yang memengaruhi beban kognitif intrinsik, beban kognitif ekstraneous, dan beban kognitif germane. Penelitian ini menggunakan pendekatan kualitatif deskriptif yang dilakukan pada mahasiswa Program Studi Teknologi Informatika yang sedang menempuh mata kuliah aljabar linear. Subjek penelitian terdiri dari 15 mahasiswa yang dipilih menggunakan teknik purposive sampling. Data dikumpulkan melalui observasi kelas, angket beban kognitif, dan wawancara mendalam. Data dianalisis menggunakan model Miles dan Huberman yang meliputi reduksi data, penyajian data, dan penarikan

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kesimpulan. Hasil penelitian menunjukkan bahwa beban kognitif intrinsik mahasiswa berada pada kategori tinggi, dengan 72% mahasiswa mengalami kesulitan dalam memahami konsep, membutuhkan usaha mental yang besar, serta memerlukan waktu yang cukup lama dalam menentukan langkah penyelesaian. Beban kognitif ekstraneous berada pada kategori sedang, dengan 46% mahasiswa mengalami kesulitan yang berkaitan dengan penyajian materi dan representasi simbolik. Sementara itu, beban kognitif germane berada pada kategori tinggi, dengan 74% mahasiswa menunjukkan upaya aktif dalam memahami konsep, menerapkan strategi yang sistematis, serta melakukan refleksi terhadap proses pemecahan masalah. Temuan ini menunjukkan bahwa meskipun mahasiswa mengalami beban kognitif intrinsik yang tinggi, mereka tetap mampu membangun pemahaman konseptual melalui keterlibatan aktif dalam pembelajaran. Penelitian ini memberikan implikasi bahwa desain pembelajaran yang terstruktur dan sistematis dapat membantu mengelola beban kognitif mahasiswa serta meningkatkan efektivitas pembelajaran matematika di perguruan tinggi.

Kata kunci: Beban kognitif; Beban kognitif ekstraneous; Beban kognitif germane; Beban kognitif intrinsik; Pembelajaran matematika.



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1. INTRODUCTION

Mathematics education in the 21st century is at a pivotal crossroads, where traditional methods of teaching are being challenged by new pedagogical approaches and technological innovations (Assencio, Vasuki, & Kumar, 2015; Mustafa, 2023). Mathematics learning in higher education is one of the fields characterized by a high level of complexity, both in terms of content structure and instructional delivery (Abdulwahed, et al., 2019; MacDonald & Thompson, 2005). Students are required to understand abstract concepts, use various mathematical symbols, and consistently connect prior knowledge with new knowledge. This situation often presents significant challenges, as human working memory capacity is limited. This condition underlies the importance of understanding students' cognitive load during mathematics learning (Azimah, Rosjanuardi, Martadiputra, 2025).

According to Cognitive Load Theory (CLT), cognitive load consists of three main types: intrinsic cognitive load, extraneous cognitive load, and germane cognitive load (Klepsch & Seufert, 2020; Tabatabaee, Jambarsang, and Keshmiri, 2024). Intrinsic load is related to the inherent difficulty or complexity of the mathematical material itself, for example, when students study linear algebra, which requires a high level of abstraction. Extraneous load arises from inappropriate instructional design, such as overcrowded learning media, poorly structured explanations, or confusing visual representations. Meanwhile, germane load refers to the cognitive load that supports schema construction, for instance, through analytical exercises, worked examples, or reflective activities that help students develop deeper conceptual understanding (Gracin & Krišto, 2022; Mao, 2025).

Recent studies indicate that cognitive load has a direct relationship with the effectiveness of mathematics learning. When intrinsic load is excessively high and not supported by appropriate instructional strategies, students tend to struggle in understanding the material and quickly feel overwhelmed (Poupard, et al., 2024; Yohanes, 2021). On the other hand, when extraneous load is minimized through well-designed instruction, students can allocate more cognitive resources to conceptual understanding, thereby increasing germane load (Wang et al., 2022). These conditions highlight the importance of examining the characteristics of students' cognitive load in mathematics learning (Gillmor, 2015).

The phenomenon of cognitive load is also influenced by the rapid development of educational technology. In recent years, mathematics learning has increasingly been delivered through digital platforms, including instructional videos, interactive media, digital presentations, and learning management systems (LMS). However, not all digital media enhance understanding. If poorly designed, digital media may instead increase extraneous load (Asmara, 2024). Students may feel overwhelmed when required to integrate information from multiple sources or interpret excessive visual elements. Therefore, understanding students' cognitive load becomes even more relevant in the era of modern digital learning.

Furthermore, students' prerequisite mathematical abilities also influence the level of cognitive load. Many informatics technology students enter the program with heterogeneous mathematical backgrounds, which affects how they understand linear algebra concepts (Cowit & Barker, 2024; Sofroniou, 2025; Wang et al., 2022). Nurjanah et al (2025) found that low foundational mathematical skills can increase intrinsic load and trigger mathematics anxiety, which in turn negatively impacts academic performance. Based on this background, the research questions of this study are (1) What are the characteristics of students' cognitive load in mathematics learning in higher education? (2) What factors influence the emergence of intrinsic, extraneous, and germane cognitive load during mathematics learning?

To address these research questions, this study employed a descriptive research approach. This approach aims to provide a clear, systematic, and factual description of students' cognitive load during mathematics learning. A descriptive approach was considered appropriate because the focus of the study is not to examine causal relationships but to map the actual conditions in the field. The problem-solving approach was conducted through several steps: (a) identifying sources of intrinsic load by analyzing the difficulty level of linear algebra material and examining students' prior knowledge; (b) measuring extraneous load by evaluating instructional delivery, clarity of examples, and organization of course materials; (c) observing germane load by examining how students construct knowledge schemas through reflective exercises, group discussions, worked examples, and step-by-step problem-solving activities; (d) using cognitive load measurement instruments, including questionnaires, cognitive load scales, interviews, and classroom observations, based on recommendations from previous research (Chen, 2023); and (e) conducting descriptive data analysis to identify patterns, major difficulties, and dominant influencing factors. Through this approach, the study is expected to provide practical recommendations for lecturers in designing more effective mathematics instruction aligned with students' cognitive capacities.

Research on cognitive load in learning has been widely conducted in recent years. These studies demonstrate how instructional design influences students' information processing, particularly in complex subjects such as mathematics. Wang et al. (2022) emphasized the importance of reducing extraneous load through well-integrated visual presentation. Chen (2023) demonstrated that worked examples help students understand problem-solving procedures while increasing germane load. Baiduri (2024) revealed that conceptual complexity in mathematics is one of the most dominant triggers of intrinsic load.

However, most previous studies have focused more on improving instructional effectiveness rather than comprehensively mapping students' cognitive load characteristics. Moreover, research on cognitive load within the Indonesian higher education context, particularly in mathematics learning, remains limited. The novelty of this study lies in several aspects: (1) providing a comprehensive mapping of students' cognitive load characteristics based on the three core components of CLT; (2) integrating instructional design, material complexity, and students' learning experiences to produce a holistic analysis; and (3) offering data-driven recommendations to minimize extraneous load and enhance germane load in mathematics learning contexts.

Through this approach, the study is expected to contribute scientifically to the development of mathematics instructional strategies aligned with students' cognitive capacities in higher education and to enrich the literature on cognitive load in mathematics education.

2. METHODS

This study employed a descriptive qualitative approach because it aims to provide an in-depth description of the characteristics of cognitive load experienced by students in studying the Linear Algebra course. The research subjects were selected using purposive sampling with the following criteria: (a) active students who attended at least 75% of Linear Algebra classes; (b) students who were

willing to participate as respondents and take part in interviews or group discussions; and (c) students with varying levels of mathematical ability (high, moderate, and low), so that variations in cognitive load could be observed. The total number of student participants was 15, while the course lecturer served as a supporting subject. The data collection procedures in this study included: (1) a Cognitive Load Questionnaire, used to identify levels of intrinsic, extraneous, and germane cognitive load. The instrument was adapted from the scale developed by Sweller, Ayres, and Kalyuga (2022) and modified to fit the context of digital mathematics learning. The questionnaire was administered after students completed core Linear Algebra topics such as matrix operations, linear transformations, and eigenvalues. (2) In-depth interviews, conducted in a semi-structured format to explore students' cognitive experiences, difficulties in understanding abstract concepts, the cognitive burden associated with the use of educational technology, and the learning strategies they employed. The interviews were conducted individually and recorded with the respondents' consent. (3) Classroom observations, carried out during face-to-face and learning sessions. Data analysis was conducted using the Miles and Huberman model, which includes: (1) Data Reduction, in which data from questionnaires, observations, and interviews were classified according to cognitive load categories: intrinsic, extraneous, and germane cognitive load.

3. RESULTS

The research findings are presented systematically based on the sources of data collection, namely: observation results to identify students' cognitive behaviors during the learning process, questionnaire results to determine students' perceptions of the cognitive load they experienced, and interview results to explore in depth students' cognitive experiences in solving Gauss–Jordan elimination problems. The presentation of these findings aims to provide a comprehensive description of the characteristics of students' cognitive load and the factors influencing it.

Furthermore, the results are organized into several sections: (1) observation results on students' cognitive load, (2) questionnaire results on students' cognitive load, and (3) findings from in-depth student interviews. These three data sources were integrated to obtain a holistic understanding of the characteristics of students' cognitive load in mathematics learning.

i) Observation Results

Observation was conducted to identify the characteristics of students' cognitive load while solving Gauss–Jordan elimination problems. The observation involved 15 students from the Informatics Technology Study Program and utilized an observation sheet consisting of 22 indicators covering intrinsic cognitive load, extraneous cognitive load, and germane cognitive load.

Tabel 1. Results of Observation Activities on Cognitive Load

Type of Cognitive Load	Very Clear (%)	Clear (%)	Moderate (%)	Slight (%)	Not Observed (%)	Category
Intrinsic Load	32%	40%	18%	10%	0%	High
Extraneous Load	15%	31%	31%	23%	0%	Moderate
Germane Load	33%	41%	19%	7%	0%	High

Based on the observation results, students' intrinsic cognitive load was categorized as high. This was indicated by 72% of students demonstrating deep thinking behaviors, rereading the questions multiple times, and requiring considerable time before initiating the solution process. Students also appeared to experience difficulties in transforming systems of equations into augmented matrix form and showed hesitation in determining the appropriate elimination steps. In addition, several students displayed expressions of confusion and made procedural errors, indicating a high cognitive demand due to the complexity of the material.

Students' extraneous cognitive load was categorized as moderate. A total of 46% of students showed signs of confusion regarding the problem format, required additional explanations from the lecturer, and revisited the provided examples. Some students also experienced difficulties in understanding matrix notation and interpreting the problem instructions. These findings suggest

that the presentation of the material and symbolic representations still imposed additional cognitive burden on some students.

Meanwhile, students' germane cognitive load was categorized as high, with 74% of students demonstrating active efforts to understand the concepts, applying systematic strategies, and rechecking their answers. Students also showed the ability to work independently and explain their solution steps logically. This indicates that students were actively engaged in the process of schema construction during learning.

Overall, the observation results indicate that students experienced high intrinsic load, moderate extraneous load, and high germane load. This suggests that although the material possessed a high level of complexity, students were still able to construct conceptual understanding through the learning process.

ii) Questionnaire Results

The cognitive load questionnaire was administered to 15 students to examine their perceptions of the cognitive load experienced during Gauss–Jordan elimination learning. The questionnaire consisted of 21 statements covering intrinsic cognitive load, extraneous cognitive load, and germane cognitive load. A 5-point Likert scale was used, ranging from Strongly Disagree (SD), Disagree (D), Neutral (N), Agree (A), to Strongly Agree (SA). The questionnaire results were analyzed in percentage form to determine the tendency and level of students' cognitive load during the learning process.

Tabel 2. Questionnaire Results on Cognitive Load

Type of Cognitive Load	SS (%)	S (%)	N (%)	TS (%)	STS (%)	Category
Intrinsic Load	37%	40%	16%	7%	0%	High
Extraneous Load	10%	29%	31%	30%	0%	Moderate
Germane Load	38%	39%	17%	6%	0%	High

The questionnaire results indicate that intrinsic cognitive load had a mean score of 3.98, categorized as high. A total of 77% of students agreed and strongly agreed that the Gauss–Jordan elimination material was difficult to understand and required substantial mental effort. Students also reported that they had to think intensively to comprehend the elimination steps and solve the given problems. These findings suggest that students' intrinsic cognitive load falls into the high category, indicating that Gauss–Jordan elimination involves significant cognitive complexity.

Extraneous cognitive load had a mean score of 2.89, categorized as moderate. Some students reported that the presentation of the material was quite helpful; however, there were still difficulties in understanding matrix symbols and interpreting problem instructions. This suggests that although the instructional presentation was relatively effective, improvements are still needed to further reduce unnecessary cognitive load (Grunwald & Corsbie-Massay, 2006). The moderate level of extraneous load indicates that the instructional design was generally adequate but still contained elements that added additional cognitive burden.

Germane cognitive load had a mean score of 4.02, categorized as high. Approximately 77% of students stated that they made active efforts to understand the Gauss–Jordan elimination concept and were able to follow the solution procedures effectively. Students also reported that their understanding improved after participating in the learning sessions and completing practice exercises. The high level of germane load indicates that students actively engaged in constructing conceptual understanding during the learning process. These findings demonstrate that although students experienced a high level of intrinsic cognitive load, they were still able to develop strong conceptual understanding through an effective learning process.

iii) Interview Results

Interviews were conducted with three students representing high, moderate, and low ability levels. The purpose of the interviews was to explore students' cognitive experiences in solving Gauss–Jordan elimination problems. The interviews were conducted after the students had completed the Gauss–Jordan elimination tasks. They aimed to identify the characteristics of

students' cognitive load based on their thinking processes, the difficulties they encountered, and the strategies they used in solving the problems. The following are the interview findings from three students representing high ability (M1), moderate ability (M2), and low ability (M3).

1. Interview with High-Ability Student (M1)

- Researcher** : What was the first thing you thought of when you saw this problem?
M1 : I immediately identified that the problem should be solved using the Gauss–Jordan elimination method, so I first converted the system of equations into an augmented matrix.
- Researcher** : Did you experience any difficulty when converting the equations into matrix form?
M1 : Not really, because I had already understood the matrix concept beforehand.
- Researcher** : How did you determine the next elimination step?
M1 : I focused on making the pivot element equal to 1 first, then eliminated the other elements in that column.
- Researcher** : Did you have to think hard during the elimination process?
M1 : Yes, especially to ensure my calculations were correct, but I am already familiar with the steps.
- Researcher** : Do you understand the purpose of the Gauss–Jordan method?
M1 : Yes, the goal is to transform the matrix into reduced row echelon form so that the solution can be seen directly.
- Researcher** : Are you confident in your answer?
M1 : Yes, because I rechecked each elimination step.
- Researcher** : What do you do when you feel uncertain?
M1 : I review the row operations I performed to make sure there are no mistakes.
- Researcher** : Do you feel your understanding improved after solving this problem?
M1 : Yes, exercises like this help me understand the concept more deeply.

Student M1 demonstrated low to moderate intrinsic cognitive load, as he was able to comprehend the complexity of the material without experiencing significant difficulty. This is evident from his immediate identification of the appropriate solution method and his ability to convert the system of equations into an augmented matrix without major obstacles. M1 also stated that he had previously understood the matrix concept, indicating that he possessed well-organized knowledge schemas in long-term memory. From the perspective of Cognitive Load Theory, when students have well-developed schemas, the number of informational elements that must be processed in working memory is reduced because the information is processed as a single unit (chunk). Therefore, although Gauss–Jordan elimination has high inherent complexity, for M1 the intrinsic load was more manageable and categorized as low to moderate.

Furthermore, M1 exhibited low extraneous cognitive load, as he did not experience difficulties related to the presentation of the material, instructions, or symbolic representations. He did not express confusion regarding the problem format or matrix notation and was able to follow the elimination procedure systematically. This indicates that the instructional design did not impose unnecessary cognitive burden on him. In contrast, M1 demonstrated high germane cognitive load, as reflected in his ability to explain the purpose of the Gauss–Jordan method, consciously determine pivot strategies, and recheck each elimination step. He did not merely execute procedures but also understood the rationale behind each step and reflected on the solution process. This suggests that a significant portion of his cognitive capacity was allocated to constructing and strengthening knowledge schemas, thereby supporting deeper conceptual understanding.

2. Interview with Moderate-Ability Student (M2)

- Researcher** : What was the first thing you thought of when you saw this problem?
M2 : I knew it was a Gauss–Jordan elimination problem, but I had to read the question several times to make sure.

- Researcher** : Did you experience any difficulty when converting the equations into matrix form?
- M2** : A little. I had to make sure all the coefficients were correct.
- Researcher** : How did you determine the elimination steps?
- M2** : I tried to make the first number equal to 1, then eliminate the numbers below it.
- Researcher** : Did you feel confused at any particular step?
- M2** : Yes, especially when I had to perform division and subtraction between rows.
- Researcher** : Did the lecturer's explanation help you understand the material?
- M2** : Yes, especially when the lecturer provided step-by-step examples.
- Researcher** : What did you do when you felt confused?
- M2** : I looked back at the examples given by the lecturer.
- Researcher** : Are you confident in your answer?**M2**: Fairly confident, but I'm still unsure whether all my steps were correct.
- Researcher** : Do you feel your understanding improved after solving this problem?
- M2** : Yes, I feel that I understand it better than before.

Student M2 demonstrated a moderate level of intrinsic cognitive load, as he understood the basic concept of Gauss–Jordan elimination but still required additional mental effort to accurately process each step. This is evident from his statement that he needed to reread the question several times and experienced some difficulty when converting equations into matrix form. He also admitted feeling confused when performing division and subtraction operations between rows. These responses indicate that the material's complexity imposed demands on his working memory, although not to the extent of preventing him from completing the solution. Within the framework of Cognitive Load Theory, this condition suggests that M2 possessed partial knowledge schemas; however, these schemas were not yet fully automated and still required relatively intensive cognitive processing.

M2 also exhibited a moderate level of extraneous cognitive load, as he still relied on examples and the lecturer's explanations to ensure correct procedures. He stated that step-by-step explanations were helpful and that he revisited examples when feeling confused. This indicates that the instructional design was supportive, yet he still required external guidance to minimize procedural confusion. Meanwhile, M2's germane cognitive load can be categorized as moderate to high, as he made active efforts to understand the solution process and recognized an improvement in his understanding after completing the task. Although he still expressed some uncertainty regarding the correctness of his steps, his responses show that part of his cognitive capacity was allocated to schema construction, though not yet as stable or well-developed as that of the high-ability student.

3. Interview with Low-Ability Student (M3)

- Researcher** : What was the first thing you thought of when you saw this problem?
- M3** : I felt that the problem was quite difficult and had to read it several times.
- Researcher** : Did you experience difficulty when converting the equations into matrix form?
- M3** : Yes, I was confused about determining the position of the numbers in the matrix.
- Researcher** : Do you understand the purpose of the Gauss–Jordan method?
- M3** : I know it is used to find the solution, but I'm still confused about the steps.
- Researcher** : Did you have to think hard during the process?
- M3** : Yes, I had to think for a long time to determine the steps.
- Researcher** : Which part did you find most difficult?
- M3** : When performing the elimination and calculating the row operations.
- Researcher** : What did you do when you felt confused?
- M3** : I looked at the examples and asked my friends.
- Researcher** : Did the lecturer's explanation help you?

- M3** : It helped, but I still need more time to understand.
Researcher : Are you confident in your answer?
M3 : Not really, because I'm afraid there might be mistakes.
Researcher : Do you feel your understanding improved after solving this problem?
M3 : It improved a little, but I still need a lot of practice.

Student M3 demonstrated a high level of intrinsic cognitive load, as he experienced difficulties from the initial stage of problem-solving. He needed to reread the question multiple times and felt confused when converting the system of equations into matrix form. He also stated that he had to think for a long time to determine the steps and struggled with performing elimination and row operations. These responses indicate that the complexity of the Gauss–Jordan elimination material imposed substantial demands on his working memory. From the perspective of Cognitive Load Theory, this condition suggests that M3 had not yet developed sufficiently strong knowledge schemas regarding matrix concepts and elimination procedures, resulting in each informational element being processed separately and overloading his cognitive capacity.

In addition, M3 exhibited moderate to high extraneous cognitive load, as reflected in his tendency to rely on examples and seek help from peers when feeling confused. Although the lecturer's explanation was helpful, he still required additional time to understand the material, indicating that the presentation and symbolic representations continued to impose extra cognitive demands. Meanwhile, M3's germane cognitive load can be categorized as low to moderate. Although he made efforts to understand the material and reported slight improvement, he lacked confidence and independence in solving the problem. His uncertainty and need for additional practice suggest that much of his cognitive capacity was allocated to managing the fundamental complexity of the material (intrinsic load), leaving limited resources for optimal schema construction (germane load).

Based on the interview results with three students of different ability levels, it can be concluded that the characteristics of cognitive load are strongly influenced by students' prior knowledge and the strength of their existing knowledge schemas. The high-ability student (M1) demonstrated relatively low to moderate intrinsic cognitive load, as he possessed a solid understanding of matrix concepts and was able to immediately identify the appropriate solution method and carry out the procedure systematically. In addition, M1's extraneous cognitive load was low because he did not experience confusion related to instructional presentation or symbolic notation. In contrast, his germane cognitive load was high, as he actively reflected on the solution steps, understood the purpose of the Gauss–Jordan method, and rechecked his work to ensure accuracy.

The moderate-ability student (M2) exhibited a moderate level of intrinsic cognitive load. Although he understood the basic concept of elimination, he still required additional mental effort to ensure procedural accuracy. M2 experienced confusion during certain row operations and relied on examples provided by the lecturer, resulting in a moderate level of extraneous cognitive load. Nevertheless, M2 demonstrated moderate to high germane cognitive load, as he made efforts to understand the solution process and recognized improvements in his understanding after practice. This indicates that part of his cognitive capacity was allocated to schema construction, although it had not yet become fully stable.

Meanwhile, the low-ability student (M3) showed high intrinsic cognitive load, as he experienced difficulties from the initial stages, such as converting equations into matrix form and determining elimination steps. The complexity of the material imposed a heavy demand on his working memory due to the lack of well-developed knowledge schemas. M3's extraneous cognitive load was categorized as moderate to high, as he relied on external assistance, such as reviewing examples and asking peers for help. His germane cognitive load was low to moderate because, although he made efforts to understand the material, his confidence and independence in solving the problem had not yet developed optimally. Overall, the interview findings indicate that the stronger a student's knowledge schemas, the more manageable the intrinsic load and the higher the germane load that supports the development of conceptual understanding.

DISCUSSION

The findings of this study indicate that students' intrinsic cognitive load in learning Gauss–Jordan elimination was categorized as high. This was reflected in observational indicators such as rereading the problem multiple times, taking a long time to begin solving, and experiencing difficulty in converting systems of equations into augmented matrix form. These findings suggest that the complexity of Gauss–Jordan elimination imposes significant cognitive demands on students. According to Cognitive Load Theory proposed by Sweller, Ayres, and Kalyuga (2022), intrinsic cognitive load is influenced by the number of informational elements that must be processed simultaneously and the level of interactivity among those elements. In this study, students were required to understand matrix concepts, perform elementary row operations, and follow elimination procedures sequentially, thereby increasing the demands on working memory.

These findings are further supported by questionnaire results indicating that students required substantial mental effort and had to think intensively to solve the problems. This suggests that intrinsic load was not only observable in students' behaviors but was also subjectively perceived by them (Schuessler, 2024). Students with lower mathematical ability tended to experience higher intrinsic load because they lacked well-developed knowledge schemas to process information efficiently. In contrast, higher-ability students were able to solve problems more systematically, as they possessed more organized knowledge structures in long-term memory.

In addition to intrinsic load, the study found that students' extraneous cognitive load was at a moderate level. This was indicated by behaviors such as asking questions about instructions, experiencing difficulty understanding matrix notation, and revisiting examples provided by the lecturer. These findings suggest that the presentation of material and symbolic representation influence students' cognitive load. According to van Merriënboer and Kirschner (2022), extraneous load arises from suboptimal instructional design and can interfere with learning if not properly managed. In this study, although some students struggled with symbolic representations, the gradual presentation of material and the provision of worked examples helped reduce unnecessary cognitive burden.

Interview results also revealed that students required additional explanations to fully understand the steps of Gauss–Jordan elimination. This highlights the important role of instructional presentation in facilitating conceptual understanding. Systematic and structured delivery of material can help students allocate working memory resources more efficiently (İbili, 2019; Jong, 2010; Pashler, et al., 2009). Therefore, effective management of extraneous cognitive load is essential for improving the effectiveness of mathematics instruction.

On the other hand, the results showed that students' germane cognitive load was categorized as high. This was reflected in behaviors such as actively attempting to understand concepts, applying systematic strategies, and rechecking answers (Davoudi, 2015). Germane load is associated with the process of schema construction in long-term memory. According to Sweller et al. (2022), germane cognitive load supports learning because it facilitates the development of conceptual understanding. In this study, students demonstrated active engagement in understanding the Gauss–Jordan elimination concept, indicating an effective learning process.

Students with high germane load exhibited deeper conceptual understanding and greater independence in problem-solving. This was evident in their ability to explain elimination steps and reflect on their solution processes. These findings suggest that although students experienced high intrinsic load, they were still able to construct strong conceptual understanding. This indicates that germane load plays a crucial role in helping students manage the complexity of the material.

Overall, the findings demonstrate that learning Gauss–Jordan elimination involves the interaction of intrinsic load, extraneous load, and germane load. The high intrinsic load was driven by the complexity of the material, the moderate extraneous load was influenced by instructional presentation, and the high germane load reflected students' active engagement in conceptual construction (Klepsch, 2017; Surbakti, 2024). These results imply that effective instruction must manage intrinsic load appropriately, minimize extraneous load, and enhance germane load (Sevcenko, 2023; Venkat, 2020). Therefore, lecturers should design structured lessons, provide clear worked examples, and encourage active student engagement to strengthen students' conceptual understanding.

4. CONCLUSION

Based on the findings of this study, it can be concluded that the characteristics of students' cognitive load in learning Gauss–Jordan elimination indicate that intrinsic cognitive load falls into the high category. This is primarily due to the complexity of the material, which requires students to understand matrix concepts, perform elementary row operations, and apply elimination procedures systematically. The results from observations and questionnaires reveal that most students required substantial mental effort, reread the problems multiple times, and took considerable time before determining the appropriate solution steps. Meanwhile, extraneous cognitive load was categorized as moderate, indicating that the instructional presentation was relatively helpful, although some difficulties remained in understanding matrix notation and the format of the problem presentation. In contrast, germane cognitive load was categorized as high, demonstrating that students actively constructed conceptual understanding through systematic strategies, reflection, and rechecking their answers. Students with stronger mathematical ability exhibited more dominant germane load, whereas those with lower ability tended to experience higher intrinsic load. Overall, these findings suggest that structured and systematic instruction can help students manage cognitive load effectively and support the development of conceptual understanding in mathematics learning.

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