STUDENT'S COGNITIVE LOAD DURING MATHEMATICS LEARNING ON SYSTEM OF LINEAR EQUATIONS IN THREE VARIABLES MATERIAL

[*1]Wafa Azimah,[2]**Rizky Rosjanuardi**,[3]**Bambang Avip Priatna Martadiputra**

[1,2,3]*Mathematics Education Study Program, Faculty of Mathematics and Science Education, Universitas Pendidikan Indonesia, Bandung, Indonesia*

Author's email:
[1]wafa.azimah@gmail.com; [2]rizky@upi.edu; [3]bambangavip@upi.edu

Corresponding author: [1]wafa.azimah@gmail.com; [2]rizky@upi.edu

Abstract. *This study aims to describe student's cognitive load during mathematics learning on the System of Linear Equations in Three Variables (SLETV) material. The approach used is descriptive qualitative with phenomenological methods to explore student's cognitive load based on their learning experiences. The subjects of the study were 24 grade X high school students, who were categorized into high, medium, and low cognitive load levels through a questionnaire. The results showed that students with high cognitive load experienced difficulties due to high intrinsic cognitive load and unmanaged extraneous cognitive load, while students with low cognitive load had a more dominant germane cognitive load, so they were better able to understand SLETV material effectively. This study emphasizes the importance of managing cognitive load in mathematics learning to improve student's understanding of complex concepts. The practical implication of this study is the need for teaching strategies that are adjusted to variations in student's cognitive load to maximize learning effectiveness.*

Keywords: *Cognitive Load, Mathematics Learning, System of Linear Equations in Three Variables*

1. INTRODUCTION

Learning is the core of developing knowledge and skills in students lives. This is a process that involves complex interactions between students, materials, and educators. Abdillah et al., (2018) stated that learning is a systematic and systemic process or activity, which is interactive and communicative between educators and students, learning resources and the environment to create conditions that allow for the cognitive process of students. In the context of mathematics education, learning becomes more challenging because it involves understanding concepts that are often abstract and require deep thought.

Mathematics learning in the curriculum not only plays a role as an integral component, but also exposes students to complex cognitive processes, including problem solving, reasoning, and critical thinking. Each stage of the student's cognitive process involves information processing, known as information processing theory in a cognitive context. Slavin (in Yohanes et al., 2016:187) stated that there are two main parts of the memory system that work in processing information, namely short-term memory and long-term memory. According to Kalyuga (2011) long-term memory has the nature of storing unlimited information, meaning it is able to store information in large quantities and for a long period of time.

In fact, each student has a different working memory capacity. This gives rise to differences in the limits of student's abilities to receive and process material. Limited working memory capacity can cause students to be burdened when the material they have to receive and process exceeds their capacity. In this context, students can be said

to experience a condition known as cognitive load. Plass, Moreno & Brunken (in Puspa et al., 2020) stated that the mental burden experienced by students with demands in the form of tasks imposed on students can cause cognitive load. Therefore, cognitive load can be interpreted as a concept that refers to the amount of cognitive resources needed by a person to process information and complete certain tasks. In the context of learning, this reflects the mental effort required by students when they interact with the subject matter. This concept has been the focus of research since it was introduced by John Sweller in 1988, and has given rise to various theories to explain various aspects of cognitive load. Cognitive load is defined by Paas, Ayres, & Pachman (2008) as a multidimensional construct that represents the burden when performing certain tasks on the cognitive system of students. Sweller (2011) stated that cognitive load is a mental effort to process information received in working memory at certain intervals.

According to Sweller (2010), cognitive load is divided into three types, namely intrinsic cognitive load, extraneous cognitive load, and germane cognitive load. Intrinsic cognitive load refers to the element of interactivity in the material. Extraneous cognitive load refers to the instructional design that burdens students in learning. Germane cognitive load refers to mental effort that is relevant to the learning process.

In reality, many students feel that they are already cognitively burdened in learning mathematics. Based on previous research conducted by Yohanes et al., (2016) describes the emergence of cognitive load in learning mathematics on geometry material including intrinsic cognitive load, extraneous cognitive load, and German cognitive load. Furthermore, Mayasari (2017) also shows that there is also a cognitive load experienced by students in learning mathematics on the material of differential equations with linear coefficients. On the other hand, Yanti & Saragiih (2023) found that student's cognitive load in learning mathematics on trigonometry material is still quite high where one of the contributing factors is because the teacher's way of explaining is too fast and also the lack of learning references. In addition to the problems found, and along with a better understanding of cognitive load, we can optimize teaching to minimize unnecessary cognitive load and facilitate better understanding. As Azimah et al., (2020) concluded that learning that minimizes extraneous cognitive load through modification of mathematics learning can improve student's problem solving abilities.

Cognitive load theory aims to predict learning outcomes by considering the abilities and limitations of human cognitive architecture (Sweller, 2010). Therefore, research on cognitive load in the context of mathematics learning has significant relevance. It opens up opportunities to understand how students experience cognitive processes when learning mathematics and how we can improve learning to reduce unnecessary cognitive load. This study aims to explore and analyze student's cognitive load in mathematics learning with a focus on SLETV material. This material was chosen because of its complexity and its integral role in mathematics learning at the secondary school level. Based on the theoretical studies that have been conducted, there has been no in-depth research examining cognitive load in mathematics learning on SLETV material, so researchers are interested in conducting research in the hope of finding the right solution to overcome student's cognitive load.

2. LITERATURE REVIEW

2.1 Cognitive Load

Cognitive load is related to the amount of mental effort in a person's working memory system when processing information. Cooper (in Sholihah, 2022: 14) defines cognitive load as the total amount of mental energy imposed on working memory at one time. According to Paas, Ayres & Pachman (2008) cognitive load is a multidimensional construct that represents the burden when performing certain tasks on student's cognitive systems.

According to Sweller (1994), cognitive load is divided into three types, namely intrinsic cognitive load, extraneous cognitive load, and germane cognitive load. Intrinsic

cognitive load is related to the inherent difficulty level of the subject matter, which cannot be changed by learning design. Extraneous cognitive load is a load that arises due to less than optimal delivery of material, such as unclear instructions or complicated presentation of information. Conversely, germane cognitive load is related to the mental effort that is relevant in building knowledge schemes and supporting the learning process (Sweller, 2010).

Previous studies have identified the role of each type of cognitive load in mathematics learning. Yanti & Saragiih (2023) showed that high extraneous cognitive load, such as delivering material too quickly, can hinder student's understanding. Conversely, optimal germane cognitive load contributes to student's problem-solving abilities (Yuniar et al., 2019). In the context of SLETV material, the complexity of the interactive elements of this material often increases student's intrinsic cognitive load, which needs to be managed with appropriate learning design to reduce extraneous cognitive load.

2.2 Mathematics Learning

Mathematics learning is a complex process that involves interactions between teachers, students, and learning materials to understand mathematical concepts, principles, and skills. This process aims to build logical, analytical, and creative thinking skills that are important in everyday life and academics (NCTM, 2000). In this process, students are not only required to understand the material but also to be able to connect the concept to real situations. According to Zulmaulida et al., (2021), mathematics learning in practice is not oriented towards mastering the material alone, but is positioned as a tool and means for students to achieve competence. According to Sholihah (2022), mathematics learning that is able to minimize student's cognitive load allows students to be able to receive learning well and can construct the knowledge gained into meaningful knowledge.

Therefore, an approach that integrates cognitive load theory is important to help students manage cognitive load when studying complex material, such as SLETV.

2.3 SLETV and Cognitive Load

System of Linear Equation in Three Variable (SLETV) is an important material in the high school mathematics curriculum because it requires logical and analytical thinking skills to solve the problems. Mayasari (2017) showed that mathematics materials involving many variables often cause high intrinsic cognitive load in students. This study supports the finding that students with weak basic understanding are more prone to confusion in identifying relevant information and developing strategies for solving SLETV problems. On the other hand, good management of germane cognitive load can improve student's ability to solve problems more effectively (Paas et al., 2003). Through proper management of intrinsic, extraneous, and germane cognitive load, teachers can help students to reduce cognitive difficulties in learning mathematics, especially in SLETV material, thereby improving their understanding and learning outcomes.

3. RESEARCH METHODS

This study aimed to describe student's cognitive load in learning mathematics on SLETV material. A descriptive qualitative approach was used, along with a phenomenological method. The qualitative approach was chosen because it described social phenomena or objects naturally, not in the form of numbers or values. The phenomenological method was employed to explore more deeply the subjective experiences of high school students related to the cognitive load they experienced when studying SLETV material. The basic purpose of phenomenology was to reduce individual experiences with a phenomenon into a description of universal essence (Creswell, 2013).

The subjects of this study were 24 grade X high school students who had studied SLETV material. From these 24 students, three students were selected to be

interviewed as the main subjects. The researcher acted as the main instrument as well as the data collector in this study. The supporting instruments used included tests, questionnaires, and interviews. The test instrument consisted of two descriptive questions on SLETV material, which were used to measure the cognitive load that arose when solving SLETV questions based on cognitive load component indicators. The questionnaire was used to obtain information from the subjects about their experiences in the learning process, which were categorized based on cognitive load criteria into three groups: high, medium, and low.

The interviews were conducted to obtain more in-depth information that was not obtained through the test questions or questionnaires. A semi-structured interview guideline was used, allowing for richer information as the interview process was relaxed and open but remained focused. The study began with preparation, including creating an initial activity plan before data collection. Data collection was carried out based on the cognitive load experienced by students while learning SLETV material. Subsequently, data processing and report writing were conducted using data analysis techniques with multiple sources of evidence or data triangulation, which included data reduction, data presentation, and drawing conclusions.

4. RESULTS AND DISCUSSION

Results study presented through categorization distribution subject student based on results calculation questionnaire cognitive load. Categorization students cognitive load is shown in Table 1.

Table 1. Recapitulation Results Questionnaire Category Student Cognitive Load

Range	Category	Frequency	Percentage (%)
Score > 71.8	High	3	13
51.9 ≤ Score ≤ 71.8	Medium	14	58
Score > 51.9	Low	7	29
Total		24	100

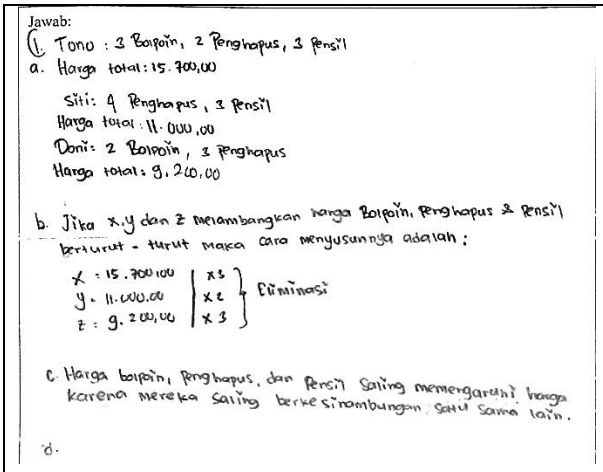
Based on Table 1, the number of students is dominant in the medium cognitive load category, namely 14 people (58%), followed by by students with low cognitive load category as many as 7 people (29%), and students with high cognitive load category as many as 3 people (13%). The results show that students experience variation cognitive load level (high , medium , and low) in learning mathematics SLETV material. The difference This level of cognitive load affects their ability to identify information relevant, compiling step solution, and solve the problem correctly.

Furthermore will served three result data analysis test and interview from subject students representing category cognitive load*:* high, medium, and low. Results election subject consists of of 3 students as can be seen in Table 3 below.

Table 2. List of Subjects Study Selected

No	Category	Code
1	High	S1
2	Medium	S2
3	Low	S3

More details will be served as follows.


Jawab:
1. Tono : 3 Bolpoin, 2 Penghapus, 3 pensil
a. Harga total: 15.700,00

Siti: 4 Penghapus, 3 Pensil
Harga total: 11.000,00
Doni: 2 Bolpoin, 3 Penghapus
Harga total: 9.200,00

b. Jika x,y dan z merambangkan harga Bolpoin, Penghapus & Pensil berturut - turut maka cara menyusunnya adalah:

x : 15.700,00 | x3
y : 11.000,00 | x2
z : 9.200,00 | x3
} Eliminasi

c. Harga bolpoin, penghapus, dan Pensil saling memengaruhi harga karena mereka saling berkesinambungan satu sama lain.

d.

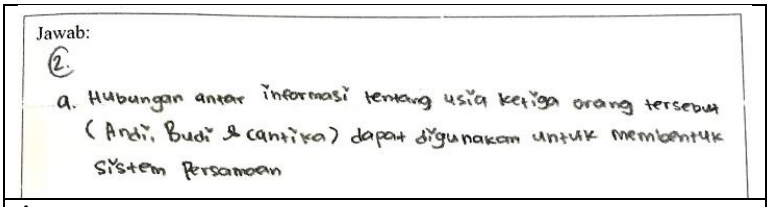
Answer:
1a. Tono: 2 Pens, 2 Erasers, 3 Pencils
Total price: IDR 15,700.00
Siti: 4 Erasers, 3 Pencils
Total price: IDR 11,000.00
Doni: 2 Pens, 3 Erasers
Total price: IDR 9,200.00
1b. If x, y, z represent the prices of pen, eraser, and pencil respectively, then the method of arranging them is

$$\left.\begin{array}{l} x = 15{,}700{,}00 \mid \times 3 \\ y = 11{,}000{,}00 \mid \times 2 \\ z = 9{,}200{,}00 \mid \times 5 \end{array}\right\} \textit{elimination}$$

1c. The prices of pens, erasers, and pencils influence each other because they are interconnected with one another.
1d. (blank)

Figure 1. Results S1 Test On Questions Number 1

Based on Figure 1, S1 is not able to solve the problem correctly. Although he can identify information from question, S1 failed to determine the form of corresponding linear equation. Reviewed from indicator information processing, S1 is not quite right in analyzing relevance information with the strategy used. He only mentioned the relationship between the variables and mentioned 'elimination' without carrying out the steps of the elimination concept or answering the questions correctly.


Jawab:
2.
a. Hubungan antar informasi tentang usia ketiga orang tersebut (Anti, Budi & cantika) dapat digunakan untuk membentuk sistem persamaan

Answer:
2a. The relationship between the information about the ages of the three people (Anti, Budi, and Cantika) can be used to form a system of equations.

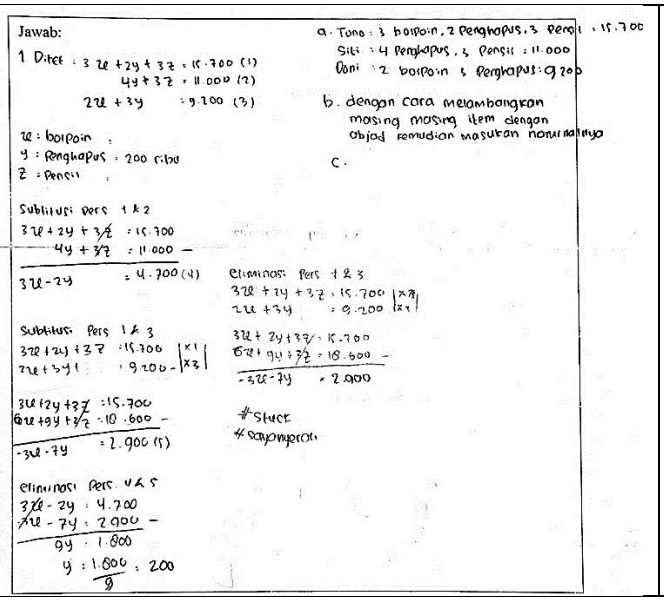
Figure 2. Results S1 Test On Questions Number 2

Based on Figure 2, S1 not fulfilled all stages according to the indicators of cognitive system, S1 only answered one from six questions with very good answers general, without showing understanding basic or business think. This indicates lack of basic understanding of mathematics and low motivation in solving question story.

The interview with S1 showed that he was unable explain his thought process while working on about SLETV because of difficulty in understanding complex instructions. This reflects high intrinsic cognitive load, caused by the complexity of SLETV material involving Lots element information, while S1 does not have foundation adequate basic concepts. The strategies used tend to origin, without understanding the right steps, and Finally give up in the middle of the process. Delivery Instructions learning that is less in line with S1 needs increases extraneous cognitive load he experienced combination complexity of the material, lack of basic understanding, and ineffective delivery causing S1 to lose focus and motivation to learn mathematics.

Results analysis work test and interview towards S1, it was found that high cognitive load tend burdened by intrinsic cognitive load and excessive extraneous cognitive load, so hinder their process of understanding. They are only able to identify part small information relevant and often fail compile step correct solution. Their answers tend to be shallow, unstructured, and does not solve problems correctly. Sweller (1994) confirms that extraneous cognitive load is disruptive learning only becomes a problem

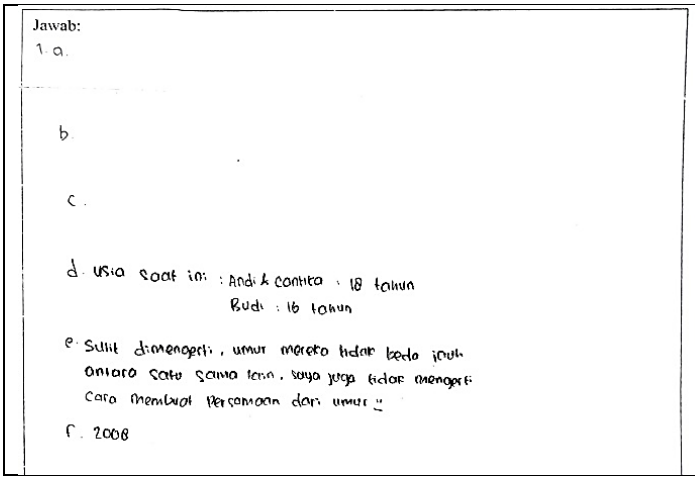
under certain conditions high cognitive load caused by interactivity element high. This reflects imbalance in the distribution of cognitive load, which hinders student utilise their potential optimally.



Answer:
1a. Tono: 2 pens, 2 erasers, 3 pencils → IDR 15,700
Siti: 4 erasers, 3 pencils → IDR 11,000
Doni: 2 pens, 3 erasers → IDR 9,200
1b. by symbolizing each item with an alphabet and then entering the nominal value:

Figure 3. Results S2 Test On Questions Number 1

Based on Figure 3, S2 is able identify information from question the story is true and compile system three linear equations variable. It succeed eliminate variable z from equations (1) and (2), yield equality new $3x - 2y = 4.700 \ldots (4)$. However, there was an error in the selection of strategy and calculation when trying again elimination in equations (1) and (3), which causes error and deadlock in finding the answer. S2 also wrong write term substitution for steps elimination is carried out.



Answer:
1d. current age: andi & cantika 18 years old
budi 16 years old
1e. difficult to understand, their ages are not much different from each other, I also don't understand how to make an equation from age
1f. 2008

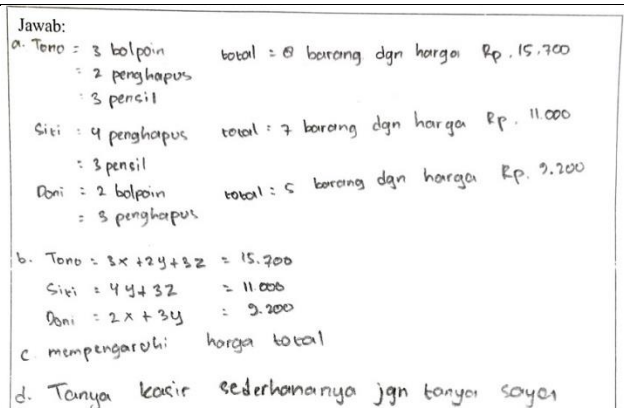
Figure 4. Results S2 Test On Questions Number 2

Based on Figure 4, S2 is not yet able to solve the problem number 2 correctly and have not fulfilled all stages based on indicator cognitive system. S2 only answered three from six questions with answers short without showing the thought process deep.

The interview with S2 regarding his thought process in working on question SLETV story shows that he capable to describe strategies such as creating equations, elimination, and substitution. However, intrinsic cognitive load seen when S2 is having trouble understand complex issues, making error, and stopped in the middle of the process because confusion. Although own motivation to learn, germane cognitive load

is not optimal because limitations focus and a sense of trust yourself. Besides that , can it is seen that extraneous cognitive load appear due to by delivery less effective instructions to worsen S2 confusion, so that He lost focus during work question.

Thus, the analysis towards S2 shows that students with medium cognitive load also influenced by intrinsic and extraneous cognitive load, but to a more moderate degree. They generally capable identify most of the information relevant and put together some steps solution correctly. However, they often fail to solve the problem completely due to error improper calculations or strategies. As for example, they can start steps solutions, such as implementing draft elimination or substitution, but Still difficulty in handling more complex issues. This shows that even though they have better understanding than students with high cognitive load, error small still hinder settlement task.



Answer:

1a. Tono: 3 ballpoint, 2 erasers, 3 pencils
Total 8 items with price IDR15,700
Siti: 4 erasers, 3 pencils
Total 7 items with price IDR11,000
Doni: 2 ballpoint, 3 erasers
Total 5 items with price IDR9,200

1b. Tono: $3x + 2y + 3z = 15{,}700$
Siti: $4y + 3z = 11{,}000$
Doni: $2x + 3y = 9{,}200$

1c. Affect the total price

1d. Ask the cashier simply, don't ask me

Figure 5. Results S3 Test On Questions Number 1

Based on Figure 5, S3 is capable identify information from question story and put it together become SLETV appropriately according to the indicators information processing. However, in the answer Number 1.d, he gives less serious answer, using sentence haphazard, which shows lack of efforts in solving questions optimally.

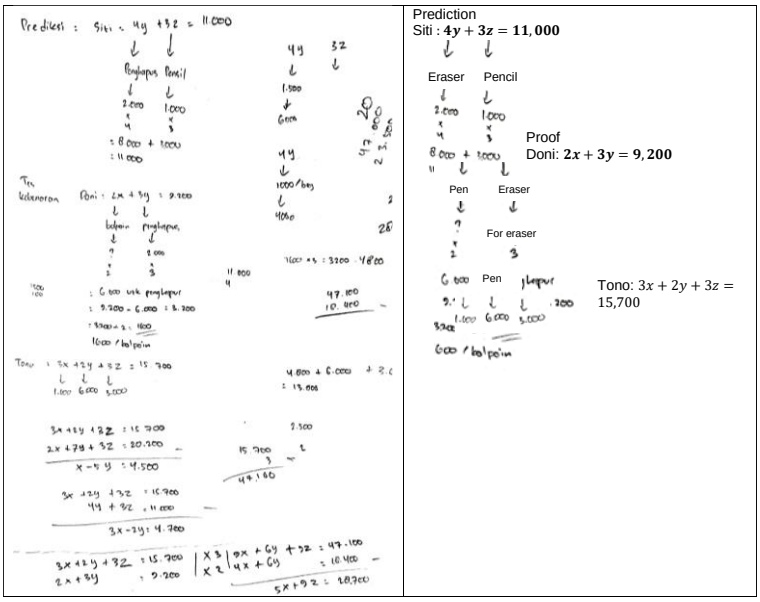


Figure 6. Results S3 Test on Questions Number 1 Continued

In Figure 6, S3 continues by analyzing strategy problem solving using approach trial and error, namely predicting and test answer through calculation mathematical. He try

apply draft elimination, even though it does not complete the process to the end. This shows improvement business compared to previously, with the ability connect information from questions with the chosen strategy. However, S3 has not succeeded determine the right end result related price every type goods.

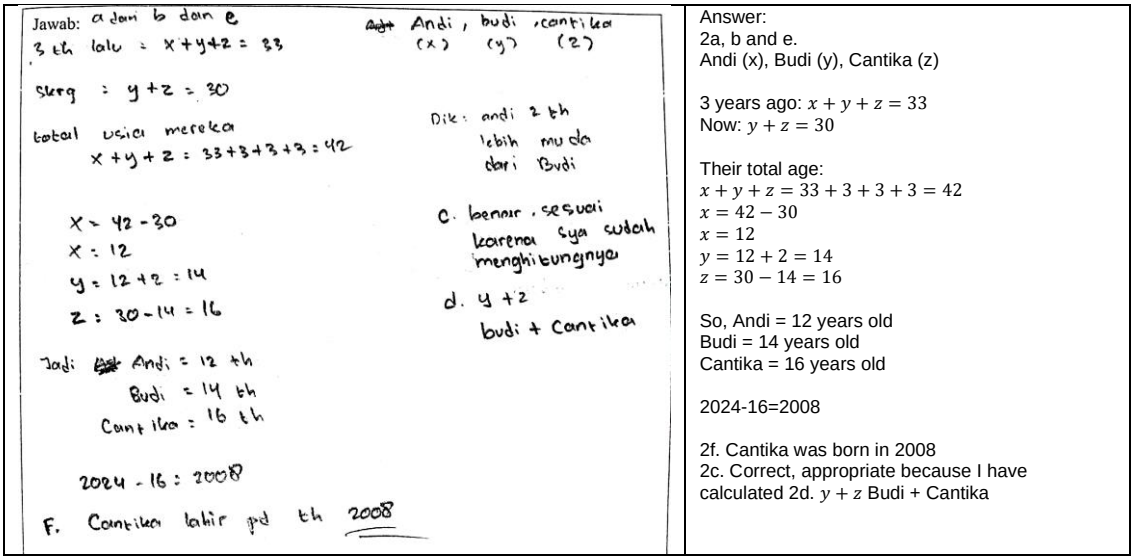


Figure 7. Results S3 Test on Questions Number 2

Based on Figure 7, S3 almost meet all stages problem solving according to indicators cognitive system. It controls steps settlement question and answer the questions correctly. Even though it is not written repeat information from question, S3 is able represent, match, and organize connection between variables in the form symbol and three linear equations variables correctly. However, S3 tends to summary and less organized in procedures problem solving. He shows existence new strategies in problem solving, even though looks difficulty presenting the strategy clearly.

The interview shows that S3 does not experience significant difficulty in understanding Instructions complex question. He often searches method fastest and most efficient to solve the problem, showing high germane cognitive load because capable organize and integrate new information into the schema his knowledge. S3 feels confident yourself with an understanding of the basic material and evaluate The teacher's explanation was effective, even though He confess difficulties in delivering the material too long or rambling.

Analysis towards S3 shows that students with low cognitive load own better ability to manage cognitive load because high germane cognitive load so that impact intrinsic and extraneous cognitive load can be minimized. They can easily identify information relevant and compile system three linear equations variables correctly. Although sometimes facing difficulties in calculations, they are able to solve the problems use simple strategyand efficient. This reflects their capacity to organize and apply knowledge in solving problems effectively. This finding is in line with the view Paas et al., (2003), who stated that a balanced distribution of cognitive load support processing information complex. This study confirms importance management cognitive load, both intrinsic, extraneous, as well as germane, to improve understanding student towards SLETV material. Good management can help students optimize capacity their cognitive abilities, so they are more effective in learning and solve SLETV questions.

CONCLUSION

This study shows that students experience variations in cognitive load levels during mathematics learning on the System of Linear Equations in Three Variables (SLETV) material, which is divided into three categories: high, medium, and low. Students with

high cognitive load tend to have difficulty understanding the relationship between variables in the SLETV due to the high intrinsic cognitive load caused by the complexity of the material and the extraneous cognitive load from ineffective instruction delivery and a distracting environment, so that they are easily distracted, confused, and cognitive fatigue. Students with medium cognitive load are generally influenced by extraneous cognitive load that is not well managed; they are able to understand most of the instructions and complete several steps of solving SLETV problems but often lose focus and strategy consistency, and feel hesitant in the middle of the process. In contrast, students with low cognitive load have a high germane cognitive load, which allows them to understand instructions, organize information, and apply solving strategies systematically and effectively. Therefore, teachers are expected to be able to understand the variations in student's cognitive load levels and adjust teaching strategies so that cognitive load management and distribution are better, so that students can more easily understand SLETV material and increase overall learning effectiveness.

REFERENCES

Abdillah, Patma Sopamena, & Fitri Tomia. (2018). BEBAN KOGNITIF SISWA DALAM MENYELESAIKAN MASALAH PERTIDAKSAMAAN LINEAR SATU VARIABEL KELAS VII MTs NEGERI AMBON. *Prosiding SEMNAS Matematika & Pendidikan Matematika IAIN Ambon Tahun 2018*, *1*(1), 83–93.

Azimah, W., Hendrayana, A., Fatah, A., & Education, M. (2020). THE EFFECT OF MODIFIED COGNITIVE LOAD THEORY PROBLEM BASED LEARNING MODELS TO PROBLEM. *Matematika Dan Pembelajaran*, *8*(2), 112–121. https://doi.org/10.33477/mp.v8i2.1366

Creswell, J. W. (2013). QUALITATIVE INQUIRY & RESEARCH DESIGN: CHOOSING AMONG FIVE APPROACHES. In *Journal GEEJ* (Vol. 7, Issue 2). SAGE Publications.

Kalyuga, S. (2011). Cognitive load theory: Implications for affective computing. *Proceedings of the 24th International Florida Artificial Intelligence Research Society, FLAIRS - 24*, 105–110.

Mayasari, N. (2017). *Beban Kognitif dalam Pembelajaran Persamaan Differensial dengan Koefisien Linier di IKIP PGRI Bojonegoro Tahun Ajaran 2016/2017*. *2*(1), 1–7.

Paas, F., Ayres, P., & Pachman, M. (2008). Assesment of Cognitive Load in Multimedia Learning: Theory, Methods, and Applications. *Recent Innovations in Educational Technology That Facilitate Student Learning*, *November*, 11–35.

Paas, F., Renkl, A. R., & Sweller, J. S. (2003). Cognitive Load Theory and Instructional Design: Recent Developments. *Educational Psychologist: A Special Issue of Educational Psychologist*, *38*(April), 1–4. https://doi.org/10.4324/9780203764770-1

Puspa, R. D., As'ari, A. R., & Sukoriyanto, S. (2020). Beban Kognitif Siswa Dalam Pembelajaran Matematika Berorientasi Pada Higher Order Thinking Skills (HOTS). *Jurnal Pendidikan: Teori, Penelitian, Dan Pengembangan*, *5*(12), 1768. https://doi.org/10.17977/jptpp.v5i12.14325

Sholihah, D. A. (2022). Strategi Pembelajaran Matematika Berdasarkan Cognitive Load Theory untuk Meminimalkan Extraneous Cognitive Load. *EQUALS: Jurnal Ilmiah Pendidikan Matematika*, *5*(1), 13–23. https://doi.org/10.46918/equals.v5i1.1197

Sweller, J. (1994). Cognitive load theory, learning difficulty, and instructional design. *Learning and Instruction*, *4*(4), 295–312. https://doi.org/10.1016/0959-4752(94)90003-5

Sweller, J. (2010). Element interactivity and intrinsic, extraneous, and germane cognitive load. *Educational Psychology Review*, *22*(2), 123–138. https://doi.org/10.1007/s10648-010-9128-5

Sweller, J. (2011). Cognitive Load Theory in Psychology of Learning and Motivation. In *The Psychology of Learning and Motivation* (Vol. 55). Elsevier Inc. https://doi.org/10.1016/B978-0-12-387691-1.00002-8

Yanti, F., & Saragiih, S. R. D. (2023). ANALISIS BEBAN KOGNITIF SISWA DALAM PEMBELAJARAN MATEMATIKA PADA MATERI TRIGONOMETRI. *Jurnal Inovasi Pendidikan Matematika*, *1*(1), 1–9.

Yohanes, B., Subanji, & Sisworo. (2016). Beban kognitif siswa dalam pembelajaran materi geometri. *Jurnal Pendidikan: Teori, Penelitian, Dan Pengembangan*, *1*(Nomor 2), 187–195.

Zulmaulida, R., Saputra, E., Munir, M., Zanthy, L. S., Wahyuni, M., Irham, M., & Akmal, N. (2021). *Problematika Pembelajaran Matematika*. Yayasan Penerbit Muhammad Zaini.