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Needs Analysis of Google Sites to Reduce Cognitive Load in Three-Variable Linear Equation Systems

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Abstract

The material of Three-Variable Linear Equation Systems (TVLES) possesses high complexity that potentially causes excessive cognitive load for students. This research is a preliminary study aimed at analyzing students' learning difficulties and mapping the requirements for developing digital learning media to reduce this cognitive load. Specifically, this study addresses two research questions: (1) which TVLES sub-skills are the most difficult and what types of errors dominate? and (2) what media feature preferences are prioritized by students and teachers? The research method employed is a descriptive quantitative-qualitative (mixed-methods) approach to provide a comprehensive overview of the subjects' conditions. The research subjects consisted of 24 tenth-grade students at SMA Negeri 13 Gowa who had completed the TVLES material in the 2024/2025 academic year. Data collection techniques utilized source triangulation, including student needs analysis questionnaires, grade document analysis, in-depth interviews, and student work error analysis using conceptual, procedural, and computational coding frameworks. The results indicated low student learning outcomes, with a class average of 68.96 and a classical mastery rate of only 33.3%. Identified difficulties were consistent with indicators of cognitive overload, particularly the inability to model word problems (88%), indicating excessive information load on working memory. Based on preference analysis, 95.8% of students stated the necessity of developing Google Sites-based media containing step-by-step explanatory videos. The research concludes that the identified design requirements suggest the development of Google Sites as a strategic direction with the potential to reduce extraneous cognitive load and facilitate independent learning.

Keywords: Cognitive load; Google sites; Three-variable linear equation systems; Digital learning media

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INTRODUCTION

Three-Variable Linear Equation Systems (TVLES) is one of the topics in high school mathematics characterized by high complexity. The nature of this material involves multiple variables, coefficients, and lengthy elimination and substitution procedures, which theoretically have the potential to cause excessive cognitive load for students. According to Sweller et al. (2019), cognitive load occurs when a student's working memory capacity is overwhelmed by the complexity of information that must be processed simultaneously. In the context of TVLES, this load arises because students must manage mathematical elements that interact intensely, which, if not managed through proper instructional design, can hinder the process of mental schema formation and knowledge transfer (Ayres, 2020; Retnowati, 2020).

TVLES occupies an important position within the senior high school mathematics curriculum because it serves as a foundation for understanding more advanced mathematical concepts, including matrices, linear programming, and mathematical modeling. Students are expected not only to perform algebraic manipulations but also to interpret contextual situations, formulate mathematical models, and apply appropriate solution strategies. Therefore, mastery of TVLES is closely related to the development of students' mathematical reasoning and problem-solving abilities. However, various studies have reported that many students continue to experience difficulties in understanding the relationships among variables and translating real-world situations into symbolic mathematical forms (Jupri & Drijvers, 2016; Wicaksono, 2023).

Students' difficulties in solving TVLES word problems often lie not only in the computational aspect but also in the stage of translating verbal language into mathematical models (Wicaksono, 2023). Errors in converting these verbal problems are frequently triggered by intrinsic cognitive load that arises when students attempt to understand complex linguistic structures before entering the procedural stage (Agustina & Santoso, 2023). This is consistent with the findings of Jupri & Drijvers (2016), which state that students' mathematization abilities are often hindered by information loads that are irrelevant to the primary learning objectives (extraneous cognitive load).

Previous studies have consistently shown that algebra learning difficulties are associated with students' inability to coordinate multiple sources of information simultaneously. Retnowati (2020) explained that students frequently experience cognitive overload when solving mathematical problems involving several interconnected elements. Likewise, Ayres (2020) emphasized that instructional materials that are not designed according to learners' cognitive architecture may unnecessarily increase cognitive burden and reduce learning effectiveness. These findings indicate that learning difficulties in algebra are not solely caused by a lack of conceptual understanding but may also be influenced by the way instructional information is presented to learners.

Although research on the use of digital media to support mathematics learning has been extensively conducted, most studies still focus on the general effectiveness of media without considering how specific media designs can mitigate students' working memory limitations (Akram, 2022). Digital learning environments should not only provide attractive visual displays but also facilitate efficient information processing. According to Mayer (2021), multimedia learning environments are more effective when instructional materials are organized according to learners' cognitive characteristics. Therefore, the design of digital learning media should pay attention to cognitive load management principles so that students can focus on essential learning information without experiencing excessive mental burden.

The utilization of web-based learning platforms has become increasingly relevant in supporting flexible and independent learning. One platform that offers considerable potential is Google Sites, which allows teachers to integrate text, images, videos, worksheets, and hyperlinks into a single learning environment. Previous studies have reported that Google Sites can improve students' learning motivation, accessibility to learning resources, and independent learning skills (Utami & Widjajanti, 2022; Suryani et al., 2022). Furthermore, the platform enables instructional content to be presented sequentially and systematically, making it suitable for implementing cognitive load reduction strategies.

There is a gap in the literature regarding how the design requirements of Google Sites-based media can be aligned with the principles of Cognitive Load Theory (CLT) to support independent learning at the high school level. Existing studies generally evaluate the effectiveness of digital learning media after implementation, while limited attention has been given to the preliminary needs analysis stage that identifies students' learning barriers and cognitive challenges before media development is conducted. In particular, studies investigating the integration of Google Sites and Cognitive Load Theory in TVLES learning remain limited, especially within the Indonesian secondary school context.

The utilization of Google Sites offers the potential to present material in a fragmented manner through the application of the segmenting principle, which can reduce extraneous cognitive load (Utami & Widjajanti, 2022). By organizing learning materials into smaller and manageable units, students can control the pace of learning according to their own cognitive capacity. Such an approach is expected to facilitate schema construction, improve understanding of mathematical concepts, and support independent learning processes.

Therefore, this study aims to conduct a needs analysis as a foundation for developing Google Sites-based media for TVLES material. This research is specifically directed to answer two research questions:

1. What are the types of learning difficulties experienced by students in TVLES material, and how do the characteristics of these errors reflect the indicators of cognitive load?
2. What are the preferences for Google Sites-based media features required by students and teachers to facilitate learning with low cognitive load?

METHOD

This study employs a descriptive approach with a combination of quantitative and qualitative data (simple mixed-method). This design was selected to provide a comprehensive overview of the subjects' cognitive conditions through the integration of quantitative data derived from test scores and qualitative data sourced from error analysis and in-depth interviews. Methodologically, this research represents the initial stage (define) of the ADDIE development model, which focuses on needs analysis to design appropriate instructional solutions.

Research Subjects

The subjects in this study were 24 tenth-grade students at SMA Negeri 13 Gowa during the odd semester of the 2024/2025 academic year. The participants consisted of 10 male students and 14 female students, with an age range of 15-16 years. Subject selection was conducted purposively, with the criteria being students who had completed the TVLES material but demonstrated learning outcomes below the minimum mastery criteria.

Ethical aspects of the research were strictly observed by guaranteeing the anonymity of all research subjects. Students' identities were anonymized using specific codes to maintain the confidentiality of personal data. Furthermore, this study obtained official permission from the authorities of SMA Negeri 13 Gowa, and participants provided their informed consent to be involved in the data collection process.

Research Instruments

Data were collected through a triangulation of techniques, which included: 1) Document analysis of daily test scores; 2) A problem-solving ability test consisting of a single complex word problem; 3) A student needs questionnaire; and 4) In-depth interviews. The deliberate use of a single complex word problem as an instrument was intended to trigger focused cognitive load, enabling the researcher to conduct an in-depth analysis of students' thought processes without distraction from other topic variations.

All instruments were validated by two mathematics education experts to ensure data validity. The summary of the validation results is presented in Table 1. The detailed blueprint for the student needs questionnaire instrument is presented in Table 2.

Table 1. Summary of Instrument Content Validation Results

No	Research Instrument	Aiken's V Coefficient	Criteria
1	Student Needs Questionnaire	0,88	Tinggi
2	Error Analysis Test	0,90	Tinggi
3	Interview Protocol	0,86	Tinggi

Table 2. Blueprint of the Media Needs Analysis Questionnaire

No	Needs Indicator	Number of Items
1	Learning experiences in TVLES material	3
2	Difficulties in processing word problem information	4
3	Media feature requirements (video, audio, simulation)	5
4	Independent learning preferences via Google Sites	3

Data Analysis

Test data were analyzed using error analysis techniques with a coding framework encompassing conceptual, procedural, and computational aspects. Quantitative data from test scores and questionnaires were processed using descriptive statistics to determine averages and mastery percentages. Meanwhile, qualitative data from interviews were analyzed through data reduction, data presentation, and verification stages to strengthen findings regarding the factors causing student cognitive load.

RESULTS AND DISCUSSION

Student Learning Profiles and Cognitive Barriers

Based on the document analysis of TVLES daily test scores at SMA Negeri 13 Gowa, a discrepancy was found between the availability of digital devices and academic achievement. Although all students (100%) possess smartphones, the learning outcomes show an average that remains below the Minimum Mastery Criteria (KKM). The descriptive statistical data are presented in Table 3.

Table 3. Descriptive Statistics of Student Learning Outcomes (N=24)

Statistics	Value
Mean Score	68.96
Maximum Score	85
Minimum Score	45
Classical Mastery (%)	33.3%
Number of Mastered Students	8 Students
Number of Non-Mastered Students	16 Students

The low classical mastery, reaching only 33.3%, indicates the presence of significant cognitive barriers in absorbing the material. A more in-depth distribution of students' ability levels is presented in Table 4 to map the groups requiring media intervention.

Table 4. Distribution of Student Ability Categories

Category	Score Range	Number of Students	Percentage
High	≥ 80	4	16,7%
Moderate	70 - 79	8	33,3%
Low	< 80	12	50,0%

Cognitive Load Diagnosis through Error Analysis

Error analysis was performed on students' work to identify the sources of cognitive load. Errors were classified into three main types according to the coding framework:

1. Conceptual Errors: Inability to identify variables and construct mathematical models from word problems.
2. Procedural Errors: Mistakes in the steps of elimination, substitution, or mixed methods.
3. Computational Errors: Errors in basic arithmetic operations (calculation).

A summary of the error types committed by the 24 students is presented in Table 5.

Table 5. Summary of Student Error Types on the TVLES Test

Error Type	Primary Indicator	Percentage/Intensity
Conceptual	Failed to model word problems into variables	High
Procedural	Mistakes in elimination and substitution steps	Very High
Computational	Errors in basic arithmetic operations	Very High

These error characteristics are further clarified through samples of student work from low, moderate, and high-ability categories, as presented in Figures 1, 2, and 3.

DIK : Adi : 11.000
Budi : 16.500
Cici : 13.000
DIT : Dedi ?
Jawab : 11.000 + 16.500 + 13.000 = 40.500 dibagi 3 orang
= 13.500

Figure 1. Visual Representation of Errors in Low-Ability Students

misal = Pensil = x
Penghapus = y
Buku = z

1> 2x+y+z = 11.000
2.> x+3y+2z = 16.500
3.> 2x+2y+z = 13.000

2x+2y+z = 13.000
2x+y+z = 11.000 −
y = 2.000

Substitusi y = 2.000
2x+0y+z = 11.000
2x+2.000+z = 11.000
2x+z = 9.000

Subtitusi y = 2.000
x+3y+2z = 16.500
x+3(2.000)+2z = 16.500
x+5.000+2z = 16.500
x+2z = 11.500

2x+z = 9.000 | x2 | 4x+2z = 18.000
x+2z = 11.000 | x1 | x+2z = 11.000 −
3x = 7.000
x = 7.000/3
x = 2.333

Figure 2. Visual Representation of Errors in Moderate-Ability Students

MIS : x : PENSIL
y : PENGHAPUS
z : BUKU
2x+y+z = 11.000 .... 1)
x+3y+2z = 16500 .... 2)
2x+2y+z = 13.000 .... 3)
ELIMINASI (3) DAN (1)
2x+2y+z = 13.000
2x+y+z = 11.000
y = 2.000

SUBTITUSI y = 2.000 KE (1) -> 2x+2.000+z = 11.000
2x+z = 9.000 .... 4)
SUBTITUSI y = 2.000 KE (2) -> x+3.(2.000)+2z = 16.500
x+3 6.000+2z = 16.5000
x+2z = 10.500 ... 5)

ELIMINASI (4) DAN (5)
2x+z = 9.000 | x2 | 4x+2z = 18.000
x+2z = 10.500 | x1 | x+2z = 10.500
3x = 7.500
x = 2.500

CARI z -> 2x+y+z = 11.000
2(2.500)+(2.000)+z = 11.000
5.000+2.000+z = 11.000
7.000+z = 11.000
z = 11.000 − 7.000
z = 4.000
HARGA 1 PENSIL : 2.500, PENGHAPUS : 2.000, BUKU : 4.000
JADI
DEDI HARUS MEMBAYAR
2.500+2.000+4.000 = 8.500

Figure 3. Visual Representation of Errors in High-Ability Students

Based on Figures 1-3, significant differences in information processing are observed. The low-category subject (Figure 1) failed to perform mathematization, indicating that cognitive overload occurred from the initial stage. Meanwhile, the moderate-category subject (Figure 2) began to lose direction during the lengthy elimination stage, suggesting that working memory capacity was being overwhelmed by the complex procedures.

Needs Analysis for Google Sites-Based Media Development

The objective findings above were validated through in-depth interviews with the subject teacher, Mrs. Hj. Nuralam, S.Pd., M.Pd., who stated:

> *"Students frequently make errors when modeling word problems into mathematical models and often commit computational mistakes due to the lengthy solution steps. The media we use is still limited to whiteboards and textbooks."* (Teacher Interview, 2025).

This condition is exacerbated by time constraints in the classroom. Subject S-05 stated:

> *"Sometimes the teacher's explanation on the whiteboard is too fast; when I am just about to write down the first step, the board is already erased for the next step."*

This evidence confirms the existence of extraneous cognitive load caused by the demands of processing verbal and visual information simultaneously. In response to these barriers, students demonstrated a very strong preference for flexible digital media. The results of the needs questionnaire are detailed in Table 6.

Tabel 6. Results of Learning Media Needs Analysis

No	Feature / Media Requirement	Student Percentage	Category
1	Accessibility via Mobile Devices (Smartphone)	100%	Highly Needed
2	Step-by-Step Explanation Videos	95.8%	Highly Needed
3	Segmented Content (Fragmented by section)	83.3%	Highly Needed
4	Independent Interactive Practice Problems	79.2%	Needed

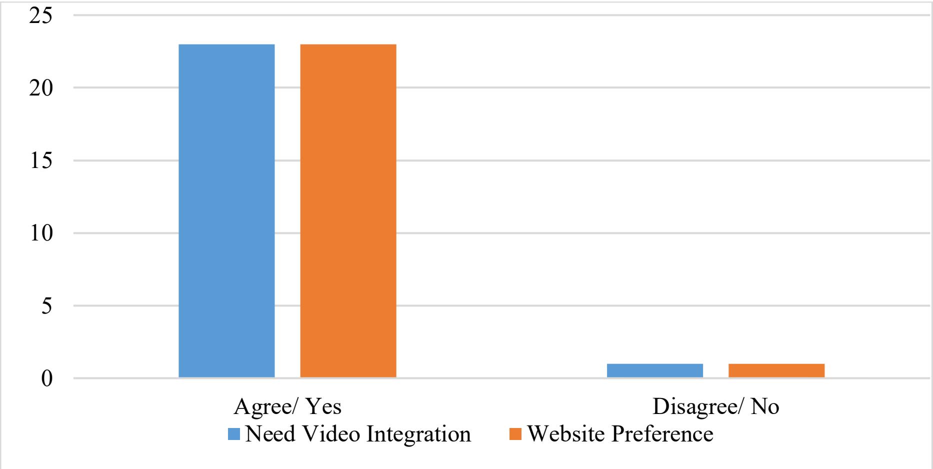

Figure 4. Graphical Representation of Digital Media Feature Requirements Percentage

Discussion: Synthesis of Findings and Cognitive Load Theory (CLT) Principles

The findings of this study indicate that the primary barrier for students in TVLES (System of Linear Equations in Three Variables) material lies in the high prevalence of conceptual errors (88%). This is consistent with the Cognitive Load Theory proposed by Sweller (2019), where the complexity of interacting elements in TVLES (multiple variables) creates a heavy Intrinsic Cognitive Load (ICL). In accordance with the foundational cognitive architectures described by Sweller (1988), learning failure drops dramatically when the limits of temporary storage are breached. When students attempt to process verbal information from word problems while simultaneously thinking about mathematical symbols, their working memory experiences an overload (Paas & Van Merriënboer, 2020). These results are supported by the research of Jupri (2021) and Wicaksono (2023), who state that the transition from natural language to symbolic language is the most critical phase in algebra. Integrating technology-driven instructional designs based on cognitive load management principles can help circumvent these integration gaps (Adesoji, 2020; Huda & Khasanah, 2021). The inability of students (S-04 and S-05) to perform modeling indicates that their mental schemas have not yet been fully formed (Martin, 2022).

The complaint from respondent S-05 regarding the teacher’s speed in erasing the whiteboard is a clear indicator of Extraneous Cognitive Load (ECL). The ephemeral nature of the teacher's explanation forces students to divide their attention between listening and note-taking (split-attention effect). As explained by Mayer (2021) in Multimedia Learning, this disruption of focus hinders the process of storing information into long-term memory. Complex technical interactions often compound this multi-source problem if the core instructions do not limit external visual overhead (Mayer & Fiorella, 2022; Plass & Kalyuga, 2019). Furthermore, optimizing instructions within these digital spaces requires structured presentation formats that adapt seamlessly to distance learning constraints (Kalyuga, 2021). Managing these variables sequentially helps optimize working memory functions within complex online networks (Sari & Wijaya, 2023; Skulmowski & Xu, 2022). This condition is further exacerbated by teaching methods that focus solely on mechanistic procedures without supporting visual reinforcement (Mutlu & Erozkan, 2021).

The development of Google Sites offers a solution through the Segmenting Principle. By breaking down TVLES material into short, structured video tutorials, students can control the pace of information according to their own capacity (self-paced learning). Observational study models confirm that video-based instructional breakdowns successfully ease the retention bottleneck compared to static textbooks (Van Gog & Rummel, 2020). Research by Suryani et al. (2022) and Chen (2024) proves that minimalist website-based media is far more effective in reducing mathematical anxiety compared to applications with excessive animations, which instead create visual distractions (Akyuz & Pala, 2021). Effective technology-based setups must leverage custom segmentation frameworks to properly reduce extraneous cognitive overhead (Siregar, 2022; Syahputra & Zulkardi, 2023).

In addition to cognitive aspects, the 100% accessibility via mobile devices indicates the infrastructure readiness of students at SMA Negeri 13 Gowa. The lightweight nature of Google Sites supports the principles of low-bandwidth learning studied by Rahmawati (2023). Digital shifts in contemporary classrooms require practical tools that facilitate baseline conceptual access across scattered home environments (Widiati & Prahmana, 2023; Yaniawati, 2020). Overall, the demand for this media is a methodological necessity to bridge the gap between students' working memory capacity and the complex TVLES material, aligning with the recommendations of Prasetyo (2024) and Zulkardi (2023) regarding the importance of personalized learning media. These structures allow digital systems to remain highly adaptive across personalized learner contexts (Ayres, 2020; Zheng, 2022).

CONCLUSION

Based on the results of the data analysis and discussion, it can be concluded that students at SMA Negeri 13 Gowa face significant learning barriers in TVLES material, characterized by low classical mastery (33.3%). Error analysis reveals that 88% of students experience high intrinsic cognitive load (ICL) during the mathematical modeling stage. Furthermore, extraneous cognitive load (ECL) was identified, triggered by the limitations of conventional media and the pace of classroom information delivery that exceeds the students' working memory capacity.

In response to these conditions, there is a necessity for the development of a website-based learning media (Google Sites) specifically designed using the segmenting principle. This media is highly required by students (95.8%) to provide structured instructional videos that can be accessed independently to reduce cognitive load and enhance student learning autonomy.

RECOMMENDATION

Mathematics teachers are encouraged to transition from static instructional media to interactive and fragmented digital media for topics with high complexity. For future researchers, it is expected that they will proceed to the development stage and conduct effectiveness testing of this Google Sites-based media in improving student learning outcomes on a broader scale.

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AUTHOR CONTRIBUTIONS STATEMENT

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Chajar Ero	✓	✓	✓	✓	✓	✓		✓	✓	✓			✓	
Irwan Akib		✓				✓		✓	✓	✓	✓	✓		
Nasrun	✓		✓	✓			✓			✓	✓		✓	✓

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

ETHICAL APPROVAL

This research involving human participants was conducted with permission from SMA Negeri 13 Gowa. All participant data were anonymized and used solely for research purposes. The study complied with institutional and national ethical standards for educational research.

DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author upon reasonable request. The data are not publicly available due to privacy considerations of research participants.

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