MIKAILALSYS
Journal of Multidisciplinary Sciences

e-ISSN : 2987-2286
p-ISSN : 2987-3924

Index: Harvard, Boston, Sydney, Copernicus, Sinta 4, Scilit, Semantic, Google, etc

https://doi.org/10.58578/mikailalsys.v4i2.10376

Reducing Extraneous Cognitive Load to Improve Analytic Geometry Problem Solving among Undergraduate Mathematics Students

Damar Rais[1], Yue Wen Yan[2], Silvie Rama Yuliane[3], Deswandhana AS[4]
[1,4]Universitas Negeri Makassar, Indonesia; [2]East China University of Technology, China;
[3]Nalanda University, Bihar, India
damar.rais@unm.ac.id; ywy@ecut.edu.cn

Article Info:

Submitted:	Revised:	Accepted:	Published:
Apr 18, 2026	May 16, 2026	May 28, 2026	Jun 2, 2026

Abstract

Mathematical problem solving in higher education requires students to coordinate symbolic, graphical, and conceptual information within limited cognitive resources. This study examines the effect of extraneous cognitive load on undergraduate mathematics students' problem-solving performance in an Analytic Geometry course and determines whether cognitively optimized task presentation can improve performance by reducing unnecessary mental effort during mathematical reasoning. A within-subject explanatory mixed-methods design was employed with 25 mathematics department students. Participants completed equivalent Analytic Geometry problem-solving tasks under two presentation conditions: a conventional format and a cognitively optimized format. Data were collected through problem-solving tests, perceived extraneous cognitive load ratings, time-on-task records, written solution analysis, and semi-structured interviews. The results showed that students achieved higher problem-solving scores in the cognitively optimized condition than in the conventional condition. They also reported lower extraneous cognitive load and completed the tasks in less time. Correlation and regression analyses indicated that higher extraneous cognitive load was associated with lower problem-solving performance, suggesting that unnecessary processing demands constrained students' mathematical reasoning. Qualitative findings supported these results by showing that students benefited from integrated diagrams, clearer symbolic representations, and reduced information search. The study concludes that extraneous cognitive load is a critical factor in undergraduate mathematical problem solving and that optimizing instructional presentation can improve cognitive efficiency without reducing mathematical rigor. These findings contribute to research on cognitive load, mathematical thinking, and educational technology, while offering practical implications for designing Analytic Geometry learning materials that support efficient and meaningful mathematical reasoning.

Keywords: Extraneous Cognitive Load; Mathematical Problem Solving; Analytic Geometry; Cognitive Efficiency; Instructional Design.

INTRODUCTION

Solving mathematical problems is one of the most challenging academic tasks because it requires students to combine understanding, procedural skills, symbolic thinking, strategic reasoning, and self-monitoring, all while working within the limits of their memory. For mathematics students, these challenges are even greater, as they often deal with abstract definitions, complex transformations, proofs, and intricate symbols. Cognitive load theory helps explain why even well-prepared students can struggle with problem solving if the way material is taught makes them process too much unnecessary information. According to this theory, how well students learn depends not just on the difficulty of the math itself, but also on how instructional materials, explanations, and digital tools are designed to either help or hinder their thinking (Sweller et al., 2019).

With the rise of digital and online learning, cognitive load has become even more important in math education. Digital textbooks, virtual labs, online tests, and multimedia can help students understand math, but they can also add distractions, confusing navigation, repeated explanations, and mismatched visuals that make learning harder (Skulmowski & Rey, 2022). These extra demands can take away from the mental energy students need to solve problems, see connections, and check their answers. This is especially true for university math students, who need to move beyond basic calculations to flexible thinking and applying math in new situations. Research shows that it is important to design learning environments that cut out unnecessary distractions while still challenging students intellectually (Ginns et al., 2020; Lavy, 2023).

This study focuses on the idea that students' struggles with math problem solving are often blamed on their ability, motivation, or practice, while the impact of extra cognitive load is often overlooked. In many math classes, students see explanations that do not match up with diagrams, examples with too many steps, symbols that are not clearly explained, or digital materials that are hard to navigate. These teaching methods do not always help students understand math; instead, they can use up the mental resources students need for reasoning and problem solving. Cognitive load theory suggests that these teaching problems can make it harder for students to build understanding and solve problems, especially when the math is new or complex (Sweller et al., 2019; Sweller 2024).

Many researchers agree that math instruction should align with how people think and learn. This means reducing unnecessary searching, connecting related ideas, sequencing tasks by skill level, and using visuals that link concepts and procedures. Students perform better when lessons emphasize core problem features rather than surface details (Ngu, 2022). Lowering extraneous cognitive load in math is not about making content easier; it is about removing confusing design elements so students can focus on understanding mathematics itself. Real mathematical thinking requires effort, but that effort should go into learning, not into overcoming poor instructional design.

Effective strategies include worked examples, combined visuals and explanations, tracing activities, virtual math labs, and well-structured digital materials. Physically or visually interacting with math representations can help transfer learning to new problems, even if it does not always directly reduce measured cognitive load (Ginns et al., 2020). Virtual math labs support exploration if they avoid unnecessary steps or confusion (Murtianto, Herlambang, & M., 2022). Clear organization of definitions, symbols, diagrams, and explanations in math texts is essential, as poor organization disrupts understanding (Lavy, 2023). Recent research distinguishes among intrinsic, extraneous, and germane cognitive load, each affecting learning differently. For mathematics education students, cognitive load relates to learning outcomes and academic level, showing that experience and prior knowledge matter when solving difficult problems (Baiduri, Hidayati, & Hidayati, 2024). Cognitive load theory also helps design lessons that guide students from problem comprehension to solution finding and explanation (Asmara, 2024).

While cognitive load theory has been widely applied in instructional design, digital learning, and math education, gaps remain. Studies have addressed word problems, geometry, math texts, virtual labs, and math literacy (Lin & Lin, 2014; Lavy, 2023; Ngu, 2022; Murtianto et al., 2022; Asmara, 2024). However, few directly examine how extraneous cognitive load affects problem solving among university mathematics students learners expected to think deeply yet still vulnerable to poor design. This study focuses on extraneous cognitive load as a primary factor in mathematical thinking, not merely a secondary issue, and is based on the premise that higher extraneous load leads to worse problem solving, especially in tasks involving problem representation, strategy selection, and justification. By targeting university math students, this research contributes to cognitive load theory, math education, and technology-based learning, exploring how students experience extraneous load, how well they solve problems, and which teaching methods support or hinder their thinking.

METHODS

A within-subject explanatory mixed methods design was utilized to examine the impact of extraneous cognitive load on mathematical problem solving among undergraduate mathematics majors. This methodology facilitated the observation of participant responses to two instructional formats for analytic geometry problems: a conventional presentation with higher potential extraneous load and a cognitively optimized presentation designed to reduce unnecessary processing demands. The design is consistent with cognitive load theory, which asserts that learning outcomes are shaped not only by task complexity but also by the organization, display, and sequencing of information for learners (Sweller et al., 2019). The mixed methods component supplemented performance data with students' accounts of their problem-solving experiences, acknowledging that perceived cognitive load may not be fully captured by test scores alone (de Bruin & van Merriënboer, 2017; Leppink, 2017).

Participants and Research Context

The study involved 25 undergraduate mathematics students enrolled in an Analytic Geometry course, which was selected because it requires integration of algebraic expressions, geometric representations, symbolic transformations, spatial visualization, and proof-oriented reasoning, therefore making it suitable for investigating extraneous cognitive load. Recent research indicates that both digital and printed learning environments can unintentionally increase unnecessary processing when learners must divide attention across multiple representations or manage excessive explanatory detail (Skulmowski & Rey, 2022; Sweller, 2024). All participants had completed prerequisite courses in calculus and linear algebra, and variation in prior competence was considered a meaningful aspect of the study rather than a source of error.

Table 1. Participant Profile and Research Context

Component	Description
Participants	25 undergraduate mathematics students
Course context	Analytic Geometry
Main topic	Lines, planes, conic sections, coordinate systems, and geometric interpretation of equations
Research focus	Extraneous cognitive load and mathematical problem solving
Design	Within subject explanatory mixed methods design
Main data sources	Problem solving test, cognitive load rating, time on task, student interviews, and written solution analysis

Instructional Materials and Task Design

The instructional materials comprised two sets of analytic geometry problem-solving tasks. Each set included problems focused on coordinate representation, equation interpretation, graphical reasoning, and explanation of solution steps. The conventional version followed a standard classroom handout format, in which definitions, diagrams, formulas, and examples were sometimes dispersed across the page. The cognitively optimized version contained identical mathematical content, but featured integrated diagrams, explicit instructions, aligned symbolic and visual representations, and minimized redundant information. This arrangement was intended to reduce extraneous cognitive load while maintaining equivalent mathematical content in both versions. The design was informed by research indicating that excessive visual searching, poorly aligned representations, and overly detailed explanations can impede students' conceptual understanding and problem-solving abilities (Sweller et al., 2019; Skulmowski & Rey, 2022). In mathematics learning, such design considerations are critical because students frequently transition between symbolic, graphical, and verbal representations when solving problems (Ngu, 2022; Lavy, 2023).

Instruments

To assess mathematical problem-solving, the researchers developed an analytic geometry test, which was reviewed by two mathematics education experts and an analytic geometry lecturer. The scoring rubric evaluated students' conceptual understanding, information representation, procedural accuracy, strategy selection, and explanation of answers. These criteria were selected because solving analytic geometry problems requires connecting geometric objects with algebraic concepts, rather than merely computing numerical answers. The scale for perceived extraneous cognitive load was adapted from educational research and assessed the clarity of instructions, ease of information retrieval, integration of representations, and the extent to which task presentation induced additional mental effort (Leppink, 2017; de Bruin & van Merriënboer, 2017). Students rated their perceived cognitive load immediately after each task. Time spent on each task was also recorded as a behavioral indicator of processing demand, though this measure was interpreted cautiously, as increased time could reflect either deeper engagement or inefficient information searching.

Research Procedure

The research procedure consisted of four main phases, as illustrated in Figure 1. Initially, students participated in an orientation session in which the study's purpose, ethical guidelines, and task format were explained. Subsequently, students completed a brief assessment to evaluate their prior knowledge of analytic geometry. Participants then solved analytic geometry tasks under two different conditions. To control for order effects, the sequence was counterbalanced: one group completed the conventional version first, followed by the optimized version, while the other group completed the tasks in the reverse order. After each condition, students completed the perceived extraneous cognitive load scale. Finally, a subset of students participated in short, semi-structured interviews regarding their understanding of the tasks, information retrieval strategies, and solution approaches. This process was designed to connect students' problem-solving performance with their cognitive processes during mathematical reasoning.

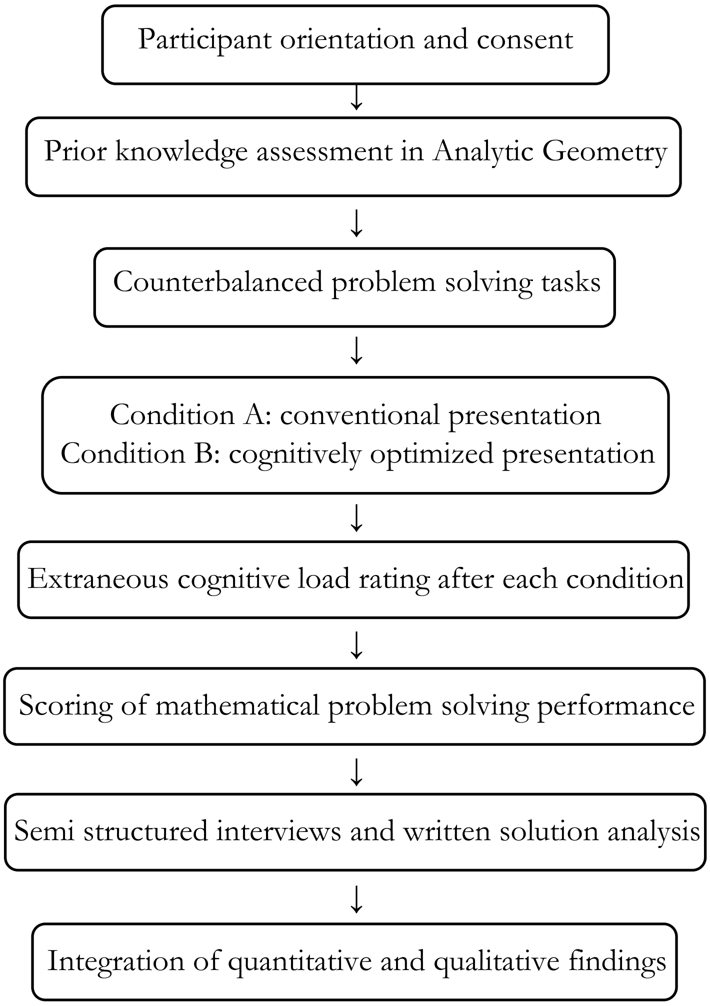

Figure 1. Research flow for examining the effect of extraneous cognitive load on mathematical problem solving in Analytic Geometry

Data Analysis

The quantitative data analysis followed several steps. First, descriptive statistics were used to summarize students' scores, perceived cognitive load, and time spent on each task. Because the sample size was small, the analysis focused on effect size, confidence intervals, and data distributions instead of significance testing. Paired comparisons were used to look at performance differences between the conventional and cognitively optimized conditions. When the data did not meet normality assumptions, a nonparametric method was used instead. To explore the link between cognitive load and performance, correlation and simple regression were used to check if higher mental effort was related to lower problem solving quality. This approach is consistent with recent research, which suggests connecting subjective load to performance and learning processes rather than treating ratings as separate responses (Skulmowski & Rey, 2022; Xu et al., 2024).

For the qualitative data, interviews and written solutions were analyzed using thematic coding. The analysis looked for signs like unnecessary searches, confusion from the layout, trouble linking equations to diagrams, and ways students managed cognitive demand. These themes were compared with quantitative results to help explain why some students improved with the optimized condition while others did not. Combining both types of evidence was important because cognitive load in math depends on task design, prior knowledge, how well students use representations, and their problem solving habits (Ngu, 2022; Lavy, 2023). The final interpretation considered whether cognitive load affected performance and how the way material was presented influenced mathematical thinking.

Validity, Reliability, and Ethical Considerations

Several steps were taken to ensure validity and reliability. Experts checked the analytic geometry tasks to make sure they were relevant and equivalent. The scoring rubric was tested, and any differences were discussed and resolved to keep scoring consistent. The internal consistency of the cognitive load scale was also checked. To support the qualitative findings, interviews, written solutions, load ratings, and scores were compared. Ethical approval was received. Participation was voluntary, and students were told the study would not affect their grades. All data were anonymized before analysis. This careful approach was important because cognitive load research needs thoughtful interpretation of mental effort and respect for participants.

RESULTS

The results cover three areas: problem solving performance, perceived cognitive load, and time spent on tasks. Table 1 provides descriptive statistics for both ways the material was presented. In the conventional condition, the average score was 75.53, while in the optimized condition, it was 85.97. This shows that students did better when the mathematical material was presented in a more integrated and efficient way. Most students also improved individually when moving from the conventional to the optimized condition, as shown in Figure 1.

Table 1. Descriptive statistics for the two instructional presentation conditions

Variable	Conventional M	Conventional SD	Optimized M	Optimized SD
Mathematical problem solving score	75.53	4.78	85.97	6.02
Extraneous cognitive load	4.97	0.74	3.10	0.67
Time on task in minutes	24.22	4.39	20.17	5.03

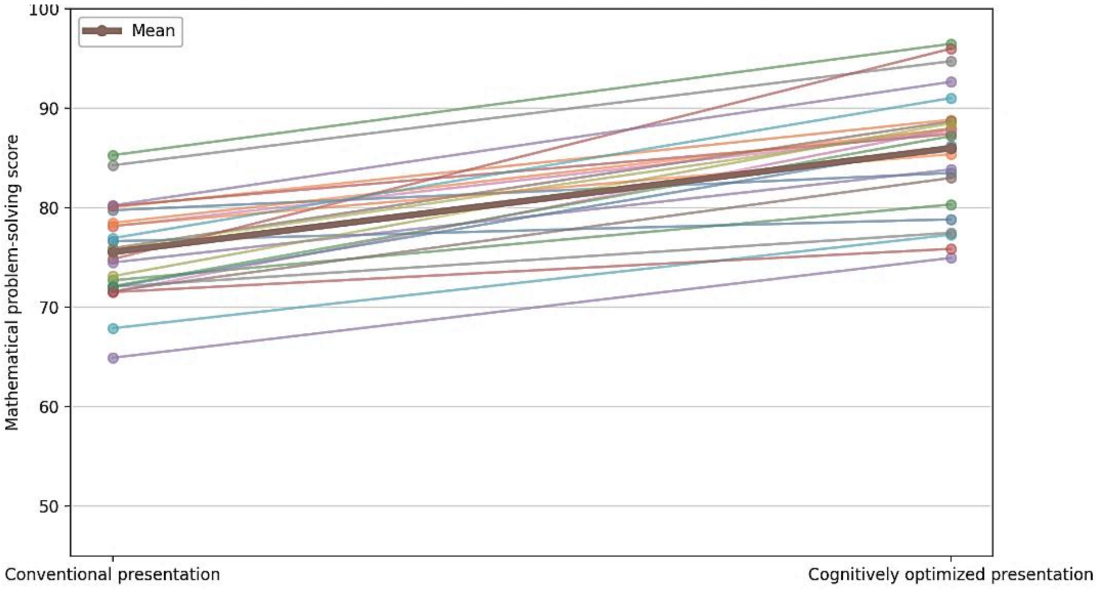

Figure 1. Changes in Analytic Geometry problem solving scores across instructional presentation conditions

The results show a clear reduction in perceived extraneous cognitive load. In the conventional condition, students reported a mean load of 4.97, suggesting the presentation format required significant mental effort beyond the mathematical content. In the optimized condition, the mean perceived extraneous load decreased to 3.10. Since both conditions used equivalent mathematical content, this reduction indicates that students found the optimized version much easier to process. The findings suggest that the difficulty stemmed not only from the intrinsic complexity of Analytic Geometry but also from the design of the learning material. Figure 2 shows that nearly all students reported lower extraneous load in the optimized condition.

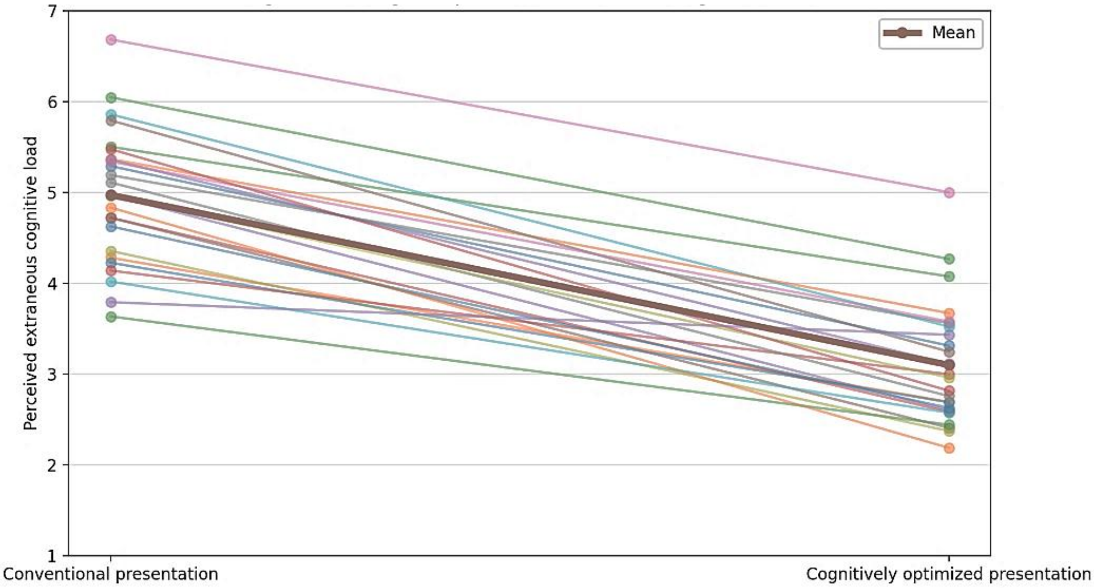

Figure 2. Changes in perceived extraneous cognitive load across instructional presentation conditions

Time on task followed a similar direction. Students spent an average of 24.22 minutes in the conventional condition and 20.17 minutes in the optimized condition. The shorter completion time in the optimized condition did not indicate superficial processing, because it occurred together with higher problem solving scores. Instead, the result suggests that students used their working time more efficiently when the task presentation reduced unnecessary search, representational confusion, and switching between disconnected pieces of information.

1. Paired comparison between conventional and cognitively optimized presentation

A paired comparison was conducted to examine whether the observed differences between the two conditions were statistically meaningful. Table 2 summarizes the paired mean differences, confidence intervals, test statistics, and standardized effect sizes. The problem solving score increased by 10.44 points from the conventional condition to the optimized condition. The difference was statistically significant, $t(24) = 12.08$, $p < .001$, with a large standardized effect size, $dz = 2.42$. The 95% confidence interval ranged from 8.66 to 12.22, indicating that the positive effect was not only statistically reliable but also educationally substantial.

Table 2. Paired comparison between conventional and cognitively optimized

Outcome	Mean difference	95% CI	t(24)	p	dz
Problem solving score	10.44	[8.66, 12.22]	12.08	< .001	2.42
Extraneous cognitive load	−1.87	[−2.09, −1.65]	−17.55	< .001	−3.51
Time on task	−4.05	[−4.83, −3.26]	−10.68	< .001	−2.14

The decrease in extraneous cognitive load was statistically significant, with a mean reduction of 1.87 points, t(24) = −17.55, p < .001, and a large effect size, dz = −3.51. This confirms that the optimized presentation effectively reduced unnecessary cognitive demand. The substantial reduction indicates that the design changes meaningfully improved how students engaged with mathematical information. Students spent less effort locating diagrams, matching symbolic expressions to visuals, and reconstructing reasoning from fragmented content.

Time on task decreased by 4.05 minutes, t(24) = −10.68, p < .001, with a large effect size, dz = −2.14. This indicates that students solved Analytic Geometry problems more efficiently under the optimized condition. The increase in performance and decrease in time suggest that the optimized presentation enabled more direct access to relevant information, allowing students to focus their mental effort on mathematical reasoning rather than navigating the task.

2. Relationship between extraneous cognitive load and problem solving performance

To assess the relationship between perceived extraneous cognitive load and problem solving quality, correlation analyses were conducted. In the conventional condition, extraneous cognitive load was negatively associated with problem solving score, r = −.51, p = .009, indicating that higher unnecessary mental effort corresponded to lower solution quality. In the optimized condition, the correlation was nearly zero, r = .02, p = .939, suggesting that improved instructional presentation reduced the impact of extraneous load on performance. Across all observations, the pooled association was strongly negative, r = −.66, p < .001, as shown in Figure 3.

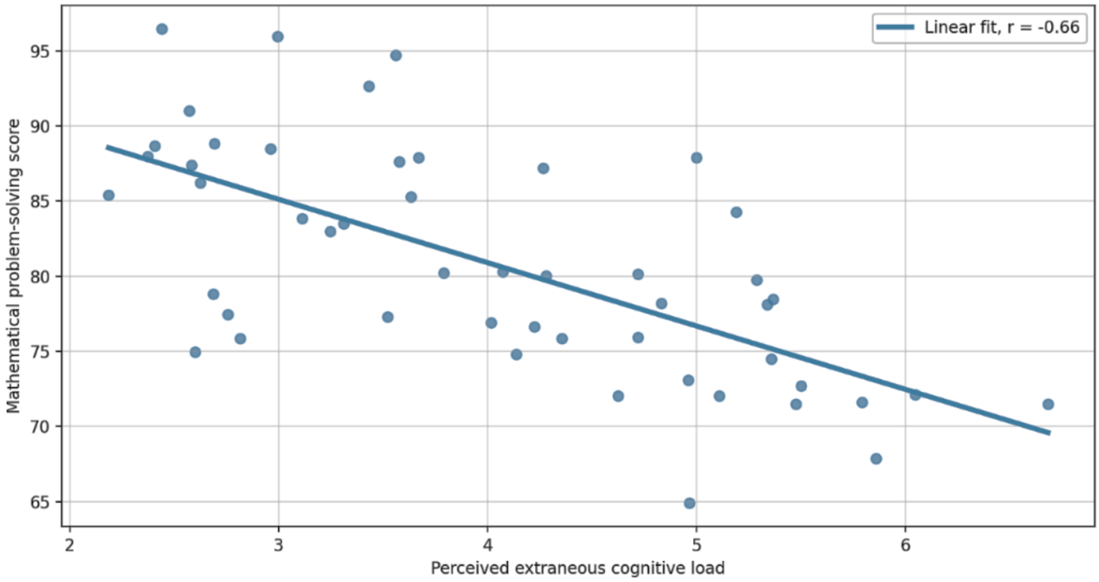

Figure 3. Association between perceived extraneous cognitive load and mathematical problem solving score.

A regression analysis was conducted to examine whether extraneous cognitive load predicted problem solving score when presentation condition and prior knowledge were considered together. The model explained 44.7% of the variance in problem solving score. Extraneous cognitive load was the strongest predictor, β = −.62, p < .001. Presentation condition and prior knowledge did not remain statistically significant after extraneous load was entered into the model. This result suggests that the improvement observed in the optimized condition was largely explained by the reduction of unnecessary cognitive burden. In other words, the instructional condition mattered because it changed how much irrelevant mental effort students had to spend during the problem solving process.

Table 3. Regression model predicting mathematical problem solving score

Predictor	Standardized β	SE	t	p
Extraneous cognitive load	−0.62	0.12	−5.25	< .001
Presentation condition	0.07	0.11	0.64	.523
Prior knowledge	−0.10	0.12	−0.81	.424

The regression pattern provides an important explanatory result. It shows that the difference between the two instructional formats was not simply a matter of students liking one format more than another. Rather, the optimized presentation appeared to reduce the cognitive interference that commonly occurs when students must coordinate equations, graphs, definitions, and procedural steps. When this interference was reduced, students were able to produce more coherent and mathematically justified solutions.

3. Analysis of students' written solutions and interview responses

The analysis of students' written work showed that the conventional condition produced more incomplete representations, disconnected procedures, and errors in translating geometric information into algebraic form. Several students correctly identified the relevant equation or diagram but failed to connect both representations in a consistent solution path. In contrast, the optimized condition led to more structured responses. Students more often began by identifying known information, linking it to the appropriate representation, selecting a relevant strategy, and verifying that the result was geometrically meaningful.

Interview responses supported this interpretation. Students described the conventional presentation as "requiring more searching" and "making it difficult to see which formula belonged to which diagram." In the optimized condition, students noted that placing diagrams near related equations helped them "see the relation faster" and "focus on solving rather than finding information." These responses suggest that reducing extraneous cognitive load improved the quality of attention during problem solving. Students were not solving easier problems, but rather equivalent problems presented in a way that made the mathematical structure more accessible.

The qualitative evidence also explained why some students still performed below the group mean in the optimized condition. These students struggled to select an appropriate strategy even after the representation was clarified. Their errors were due less to searching for information and more to conceptual gaps in Analytic Geometry. This distinction is important because it separates difficulties caused by instructional presentation from those caused by insufficient conceptual understanding. The optimized condition reduced unnecessary processing but did not remove the need for strong mathematical knowledge.

4. Integrated interpretation of the findings

Overall, the findings show that extraneous cognitive load significantly affected mathematical problem solving among Analytic Geometry students. The cognitively optimized presentation improved problem solving performance, reduced perceived extraneous load, and shortened time on task. The strongest statistical evidence was the large reduction in extraneous load and its negative association with problem solving performance. Qualitative evidence added depth by showing that students benefited from integrated representations, clearer visual alignment, and reduced information search.

The overall pattern indicates that mathematical problem solving is sensitive to instructional design. When learning materials impose unnecessary cognitive demands, students may appear less capable because part of their working memory is consumed by presentation-related difficulties. Reducing these demands allows students to focus more on mathematical reasoning, representation, and justification. This finding is especially relevant for Analytic Geometry, where problem solving relies on coordinating symbolic and spatial information. The results support the need for instructional designs that maintain mathematical rigor while reducing avoidable cognitive burden.

DISCUSSION

1. Extraneous cognitive load as a constraint on mathematical problem solving

The findings show that students' performance in Analytic Geometry depends not only on their mathematical knowledge but also on the cognitive conditions in which they solve problems. The improvement seen with the cognitively optimized presentation supports cognitive load theory: reducing unnecessary processing allows learners to focus working memory on schema construction, representation, and strategic reasoning (Sweller et al., 2019). This is especially relevant in Analytic Geometry, where students must coordinate equations, coordinate systems, visual representations, and logical justification. Poor organization of these elements can make tasks seem more difficult, even when students understand the underlying concepts. This interpretation is supported by recent evidence showing that task complexity can shape learners' performance, cognitive load, and awareness during problem solving (Zeitlhofer et al., 2024). It is also consistent with research on visual reference information, which indicates that visual support can improve solution quality when it clarifies task requirements but may become cognitively costly when it introduces irrelevant or excessive processing demands (Zhong et al., 2026). In this sense, the present findings suggest that visual and symbolic representations in Analytic Geometry should be treated as cognitive design elements rather than as neutral additions to the learning material.

This result aligns with recent research emphasizing that instructional design is a key part of the cognitive environment for mathematical reasoning. Sweller (2024) noted that differences in prior knowledge and processing capacity affect how learners respond to instructional materials. This study extends their argument to university mathematics students, showing that even those who have completed prerequisite courses remain affected by extraneous load. Being a mathematics major does not guarantee protection from inefficient presentation. This finding also supports Skulmowski & Xu (2022), who cautioned that digital and online materials can increase unnecessary processing if not designed to match human cognitive architecture. Recent studies on technology supported learning further reinforce this point. Rule integrated tutoring systems for mathematical problem solving show that digital support must be structured by clear pedagogical principles to avoid opaque, unstable, or cognitively inefficient guidance (Looi et al., 2026). Similarly, research on neurodiversity and cognitive load in online learning shows that confusing navigation, inaccessible content presentation, and poorly synchronized learning resources can create additional cognitive barriers, particularly for learners with different cognitive profiles (Le Cunff et al., 2024). The growing use of artificial intelligence and neurophysiological tools to classify cognitive load also indicates that cognitive burden is increasingly recognized as a measurable design and performance issue in complex learning environments (Khan et al., 2024). Therefore, the present study strengthens the claim that reducing extraneous cognitive load is not merely a matter of improving visual appearance, but a substantive instructional condition for supporting mathematical problem solving.

2. The role of representation in Analytic Geometry learning

A key implication is that mathematical representation is integral to the reasoning process, not just a means of communication. In the conventional format, students had to search across separate equations, diagrams, and text, hindering their ability to develop coherent solutions. The optimized presentation enabled students to connect symbolic and visual information more efficiently. This supports broader research indicating that effective problem solving relies on coordinating multiple representations rather than processing each one in isolation (Ngu, 2022; Lavy, 2023). Recent work in adjacent computational domains also reinforces the importance of representational geometry. Hyperbolic dual geometry alignment has been shown to improve knowledge aware recommendation by aligning relational structures across representational spaces, suggesting that the geometry of representation can affect how complex relational information is organized and retrieved (Zhang et al, 2026). Similarly, research on neural representation indicates that manifold geometry can shape how high dimensional information is structured, compressed, and used for cognitive and behavioral performance (Zhu et al., 2026). Although these studies are not situated in mathematics education, they support the broader argument that representational structure is not neutral; it shapes how information is processed, connected, and acted upon.

This result is consistent with Lin & Lin's (2014) findings that understanding configurations in computer supported geometry can create significant cognitive demands. In Analytic Geometry, students must interpret equations geometrically, identify graphical structures, and transform them for reasoning. When instructional materials separate these elements, students' attention is divided. This study shows that an integrated format leads to better performance and lower perceived load. Mathematical representations should not be oversimplified; instead, they should be designed to focus students' effort on mathematical structure rather than on finding and matching fragmented information. Evidence from image based deep learning further supports this point: when discrete accident features were transformed into structured image representations and processed using a virtual geometry group based architecture, predictive performance improved because the representation made latent feature relations more accessible to the model (Sonnatthanon & Choocharukul, 2025). In the present study, the educational implication is analogous: when mathematical information is represented in a spatially and symbolically coherent format, students can allocate more cognitive resources to reasoning, transformation, and justification rather than to unnecessary representational search.

3. Alignment with and extension of previous cognitive load research

The findings confirm that extraneous cognitive load can hinder mathematical problem solving, even among students who are capable of engaging with advanced mathematical content. This supports the argument that unnecessary cognitive activity can consume limited working memory resources and disrupt learning (Sweller et al., 2019). In the Indonesian mathematics education context, Asmara et al. (2024) also showed that cognitive load theory can inform the design of mathematical literacy processes, while Oktaviyanthi et al. (2024) demonstrated that cognitive load can be validly measured in advanced mathematical topics such as the formal definition of limit.

The results also align with Ginns et al. (2020), who found that well-designed representational interaction can support problem solving. In this study, the optimized format reduced unnecessary searching and helped students connect equations, diagrams, and conceptual information more efficiently. Similar findings are reflected in Murtianto et al. (2025), who showed that instructional prompts in mathematics multimedia learning can reduce cognitive load, and Funny & Rahmawati (2025), who found that students may experience different cognitive load profiles during mathematics learning.

However, reducing extraneous load does not automatically solve all mathematical difficulties. Some students still showed weak performance, indicating that conceptual understanding and prior knowledge remain essential. This is consistent with the distinction between intrinsic and extraneous cognitive load (Sweller et al., 2019; Sweller et al., 2024). Oktaviyanthi et al. (2024) further showed that mathematical learning involves complex cognitive processing, while Aprillia & Retnowati (2025) found that task format can affect retention, transfer, and cognitive load. Thus, the optimized presentation improved cognitive efficiency, but strong mathematical understanding and well-structured practice remain necessary.

4. Implications for digital mathematics learning design

The findings have clear implications for the design of digital and printed materials in university mathematics courses. Instructional designers should view extraneous cognitive load as a measurable and modifiable issue. Analytic Geometry materials should integrate diagrams and equations, avoid redundant explanations, reduce visual clutter, and focus attention on relevant mathematical relationships. This aligns with Skulmowski & Rey's (2022) analysis of cognitive load in online learning and Murtianto et al. (2022) review of cognitive load theory in virtual mathematics labs. It is also supported by Asmara et al. (2024), who showed that mathematical learning processes can be designed through cognitive load theory, and Oktaviyanthi et al. (2024), who validated cognitive load measurement in advanced mathematical content. Digital environments can support exploration and visualization only if interface design does not add burdens that distract from reasoning. In this respect, Murtianto et al. (2025) further demonstrated that mathematics multimedia learning can reduce cognitive load when instructional prompts are carefully embedded into the learning environment.

The findings also suggest that cognitive load measures should be included in evaluations of educational technology. Many digital learning tools are evaluated primarily through achievement scores or satisfaction surveys. This study shows that perceived extraneous load can more precisely explain why one design supports problem-solving better than another. This aligns with de Bruin & van Merriënboer (2017), who advocated stronger links between cognitive load research and self-regulated learning. If students can identify which design features increase unnecessary mental effort, they may become more strategic in choosing resources and managing their learning. This implication is consistent with Funny & Rahmawati (2025), who mapped students' cognitive load profiles in realistic mathematics education, and Aprillia & Retnowati (2025), who found that problem presentation and guided questions can influence retention, transfer, and cognitive load. Thus, digital mathematics learning design should be evaluated not only by whether students achieve correct answers, but also by whether the learning environment helps them use cognitive resources efficiently.

5. Theoretical contribution and limitations

This study reinforces the idea that mathematical thinking is shaped by instructional conditions. It contributes to cognitive load theory by showing that extraneous load is not only a design factor in multimedia learning but also predicts problem-solving quality in undergraduate mathematics. The study also shows that difficulties in Analytic Geometry can result from the interaction between conceptual complexity and representational design. This perspective avoids attributing students' errors solely to lack of ability or effort.

Nevertheless, the study has limitations. The sample consisted of 25 mathematics students from one course context, so generalization should be made cautiously. The within-subject design strengthened the study, but it has limitations. The sample included 25 mathematics students from a single course, so generalization should be cautious. The within-subject design increased sensitivity to instructional differences, but future research should use larger samples, multiple institutions, and a wider range of mathematical topics. It would also be useful to examine whether similar effects occur in proof-based courses, abstract algebra, calculus, or real analysis, where extraneous load may have different sources. Future studies could combine subjective load ratings with eye-tracking, process data, or screen interaction logs to better understand how students allocate attention during problem-solving. The results do not suggest that mathematics should be made easier, but rather that instructional design should allow students to allocate their limited cognitive resources to mathematical reasoning rather than to avoidable representational confusion.

CONCLUSION

This study demonstrates that extraneous cognitive load plays a meaningful role in shaping undergraduate students' mathematical problem solving in Analytic Geometry. Students performed more effectively when tasks were presented in a cognitively optimized format, as reflected in higher problem solving scores, lower perceived extraneous cognitive load, and shorter time on task. These findings indicate that students' difficulties in solving mathematical problems are not always caused by insufficient mathematical ability alone, but may also arise from unnecessary cognitive demands created by poorly organized instructional materials. In Analytic Geometry, where students must coordinate equations, diagrams, symbolic forms, and conceptual relationships, fragmented or unclear presentation can consume working memory resources that should otherwise be used for reasoning, strategy selection, and justification. Therefore, reducing extraneous cognitive load does not simplify mathematics; rather, it allows students to engage more directly with the essential mathematical structure of the task.

The study contributes to the literature on cognitive load theory, mathematical thinking, and educational technology by showing that instructional design is a critical condition for effective mathematical problem solving in higher education. The findings suggest that lecturers and instructional designers should carefully integrate visual and symbolic representations, reduce redundant information, and structure learning materials to support cognitive efficiency. This study also offers practical implications for the development of Analytic Geometry resources that preserve mathematical rigor while minimizing avoidable processing demands. Future research should involve larger samples, multiple institutions, and different mathematical domains such as calculus, abstract algebra, real analysis, or proof based courses. Further studies may also use eye tracking, screen recordings, think aloud protocols, or learning analytics to examine how students allocate attention and manage cognitive load during mathematical problem solving.

REFERENCES

Aprillia, F., & Retnowati, E. (2025). Do goal-free problems with guided questions affect retention, transfer, and cognitive load? *Edumatica: Jurnal Pendidikan Matematika, 15*(3), 296–309. https://doi.org/10.22437/edumatica.v15i3.45657

Asmara, A. S., Waluya, S. B., Suyitno, H., Junaedi, I., & Ardiyanti, Y. (2024). Developing patterns of students' mathematical literacy processes: Insights from cognitive load theory and design-based research. *Infinity Journal, 13*(1), 197–214. https://doi.org/10.22460/infinity.v13i1.p197-214

Baiduri, Holisin, I., Inganah, S., & Hidayati, W. S. (2024). The impact of cognitive load on learning achievement and semester level in mathematics education students. *Journal of Hunan University Natural Sciences, 51*(8), 19–35. https://doi.org/10.55463/issn.1674-2974.51.8.2

de Bruin, A. B. H., & van Merriënboer, J. J. G. (2017). Bridging cognitive load and self-regulated learning research: A complementary approach to contemporary issues in educational research. *Learning and Instruction, 51*, 1–9. https://doi.org/10.1016/j.learninstruc.2017.06.001

Funny, R. A., & Rahmawati, F. K. (2025). Mapping cognitive load profiles in realistic mathematics education: A study with aerospace engineering students. *Jurnal Elemen, 11*(4), 1018–1029. https://doi.org/10.29408/jel.v11i4.32104

Ginns, P., Hu, F.-T., & Bobis, J. (2020). Tracing enhances problem-solving transfer, but without effects on intrinsic or extraneous cognitive load. *Applied Cognitive Psychology, 34*(6), 1522–1529. https://doi.org/10.1002/acp.3732

Khan, M. A., Asadi, H., Zhang, L., Qazani, M. R. C., Oladazimi, S., Loo, C. K., Lim, C. P., & Nahavandi, S. (2024). Application of artificial intelligence in cognitive load analysis using functional near-infrared spectroscopy: A systematic review. *Expert Systems with Applications, 249*, Article 123717. https://doi.org/10.1016/j.eswa.2024.123717

Lavy, I., & Shriki, A. (2023). On reading mathematical texts, question-asking and cognitive load. *Education Sciences, 13*(7), Article 678. https://doi.org/10.3390/educsci13070678

Le Cunff, A. L., Giampietro, V., & Dommett, E. (2024). Neurodiversity and cognitive load in online learning: A systematic review with narrative synthesis. *Educational Research Review, 43*, Article 100604. https://doi.org/10.1016/j.edurev.2024.100604

Leppink, J. (2017). Cognitive load theory: Practical implications and an important challenge. *Journal of Taibah University Medical Sciences, 12*(5), 385–391. https://doi.org/10.1016/j.jtumed.2017.05.003

Lin, J.-H., & Lin, S. S. J. (2014). Cognitive load for configuration comprehension in computer-supported geometry problem solving: An eye movement perspective. *International Journal of Science and Mathematics Education, 12*(3), 605–628. https://doi.org/10.1007/s10763-013-9479-8

Looi, C.-K., Liu, Z., & Sun, D. (2026). Taming the black box: Design principles for rule-integrated LLM tutoring systems in primary school mathematical problem solving. *Computers and Education: Artificial Intelligence, 10*, Article 100586. https://doi.org/10.1016/j.caeai.2026.100586

Murtianto, Y. H., Herlambang, B. A., & Muhtarom. (2022). Cognitive load theory on virtual mathematics laboratory: Systematic literature review. *KnE Social Sciences, 7*(19), 413–420. https://doi.org/10.18502/kss.v7i19.12461

Murtianto, Y. H., Retnowati, E., & Hanham, J. (2025). Reducing cognitive load using social persuasion prompts in mathematics multimedia learning. *Jurnal Pendidikan Matematika, 19*(3), 465–488. https://doi.org/10.22342/mej.v19i3.pp465-488

Ngu, B. H., & Phan, H. P. (2022). Developing problem-solving expertise for word problems. *Frontiers in Psychology, 13*, Article 725280. https://doi.org/10.3389/fpsyg.2022.725280

Oktaviyanthi, R., Agus, R. N., & Khotimah. (2024). Exploring the link between cognitive load and brain activity during calculus learning through electroencephalogram (EEG): Insights from visualization and cluster analysis. *Journal on Mathematics Education, 15*(4), 1383–1408. https://doi.org/10.22342/jme.v15i4.pp1383-1408

Oktaviyanthi, R., Agus, R. N., Garcia, M. L. B., & Lertdechapat, K. (2024). Cognitive load scale in learning formal definition of limit: A Rasch model approach. *Infinity Journal, 13*(1), 99–118. https://doi.org/10.22460/infinity.v13i1.p99-118

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

Skulmowski, A., & Xu, K. M. (2022). Understanding cognitive load in digital and online learning: A new perspective on extraneous cognitive load. *Educational Psychology Review, 34*(1), 171–196. https://doi.org/10.1007/s10648-021-09624-7

Sonnatthanon, N., & Choocharukul, K. (2025). Crash severity prediction using a virtual geometry-group-based deep learning approach with images-based feature representation. *Results in Engineering, 27*, Article 106155. https://doi.org/10.1016/j.rineng.2025.106155

Sweller, J. (2024). Cognitive load theory and individual differences. *Learning and Individual Differences, 110*, Article 102423. https://doi.org/10.1016/j.lindif.2024.102423

Sweller, J., van Merriënboer, J. J. G., & Paas, F. (2019). Cognitive architecture and instructional design: 20 years later. *Educational Psychology Review, 31*(2), 261–292. https://doi.org/10.1007/s10648-019-09465-5

Zeitlhofer, I., Zumbach, J., & Schweppe, J. (2024). Complexity affects performance, cognitive load, and awareness. *Learning and Instruction, 94*, Article 102001. https://doi.org/10.1016/j.learninstruc.2024.102001

Zhang, S., Zhao, S., Zhang, Q., & Song, Y. (2026). HyDRA: Hyperbolic dual-geometry representation alignment for knowledge-aware recommendation. *Neurocomputing, 693*, Article 133848. https://doi.org/10.1016/j.neucom.2026.133848

Zhong, Y., Li, Y., Luo, P., & Jie, S. (2026). Effects of visual reference information on solution quality in crowdsourcing contests: A cognitive load perspective. *International Journal of Information Management, 88*, Article 103048. https://doi.org/10.1016/j.ijinfomgt.2026.103048

Zhu, J., Zhu, M., Wu, P., He, Q., Wang, J., Niu, X., & Wang, Z. (2026). The geometry of neural representation: From neural tuning to manifold geometry. *Chaos, Solitons & Fractals, 208*, Article 118193. https://doi.org/10.1016/j.chaos.2026.118193