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Exploration of Students' Mathematical Creative Reasoning Based on Extraneous Cognitive Load in Geometry Learning

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Abstract

Creative reasoning and cognitive load management are two essential aspects in learning mathematics because they directly affect students' ability to understand concepts, develop solving strategies, and produce innovative solutions to mathematical problems. This study aims to explore the relationship between extraneous cognitive load and creative reasoning ability of elementary school students in solving geometry problems. This research used a qualitative approach with a case study design. The research subjects were 27 elementary school students who have learned the material of building space. Data were collected through extraneous cognitive load questionnaire, mathematical creative reasoning test, and interviews. Data analysis was done descriptively and thematically with reference to three indicators of creative reasoning, namely mathematical foundation, plausibility, and novelty, as well as five indicators of extraneous cognitive load: split attention, redundancy, transiency, advanced learner, and inadequate prior knowledge. The results showed that the higher the extraneous cognitive load experienced by students, the lower the creative reasoning score they achieved. Students with low extraneous cognitive load were able to understand information, develop logical strategies, and produce original solutions. In contrast, students with high extraneous cognitive load had difficulty understanding instructions, made mistakes in choosing strategies, and did not show flexible thinking skills. These findings reinforce the importance of learning design that takes into account students' cognitive working capacity. The implication of this research leads to the importance of teachers designing geometry lessons that have minimal instructional load, using effective visual media, and composing questions that are in accordance with students' abilities so that the creative thinking process can develop optimally.

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INTRODUCTION

Mathematical creative reasoning ability is one of the Higher Order Thinking Skills that needs to be developed early on. This ability allows students to develop original problem solving strategies, either through the creation of new solutions, or modifications to the steps of concepts, formulas, or algorithms that have been learned (Agusti et al., 2023; Jonsson et al., 2022; Kusaeri et al., 2022; Olsson & Granberg, 2024). Eriksson & Sumpter, (2021); Permatasari et al., (2020) emphasized that creative reasoning is indispensable in the context of non-routine mathematics learning including at the elementary school level. This ability not only helps students in achieving a deeper understanding of the material, but also increases their flexibility of thinking in dealing with various types of mathematical problems.

Geometry is one of the mathematics materials that demand creative thinking skills. In learning geometry, students are required to understand the concepts of space and shape, visualize, and manipulate, and represent geometric shapes flexibly. Agusti & Suhendra, (2023); Dhlamini et al., (2019) asserted that mathematical reasoning in geometry includes manipulation of space, representation, and rationalization of geometric objects. Geometry tasks that emphasize spatial representation can be a stimulus for the birth of creative strategies (Anggraeni et al., 2025; Arto et al., 2025; Masfingatin et al., 2020; Ulya et al., 2024). However, in practice, learning geometry often presents significant challenges for students due to the complexity of the material to be understood and the visualization skills required. Difficulties in understanding geometry concepts can hinder students in developing creative problem solving. As a result, not all students can develop creative reasoning optimally, which has implications for their low ability to find innovative solutions to geometry problems.

One important factor that is believed to affect students' creative thinking ability in learning geometry is cognitive load. Cognitive load refers to the amount of information that must be processed in working memory during learning. It is added by Kalyuga & Plass, (2017) that cognitive load is the load capacity received by human cognition caused by task demands that exceed capacity. Cognitive load is divided into three main types: intrinsic cognitive load, germane cognitive load, and extraneous cognitive load. Extraneous cognitive load refers to mental load caused by inappropriate instructional design such as confusing presentation of material, unsystematic instruction, and use of overly complex media (Gupta & Zheng, 2020; Kalyuga & Plass, 2017). This load is not directly related to the core material being learned, but it can disrupt students' thought processes and drain working memory capacity that should be used to understand and solve problems (Suherman et al., 2021; Syafril et al., 2021).

In learning geometry in elementary school, extraneous cognitive load can arise when the presentation of material is not appropriate for students' cognitive developmental level. The use of complex illustrations, ambiguous instructions, or a lack of coherent stages of explanation, can cause students to focus more on understanding instructions than exploring solutions creatively (Gupta & Zheng, 2020). For example, the use of overly complex learning media, unsystematic presentation of information, and overly difficult tasks without clear learning stages can divert students' attention from problem solving to understanding the task itself. These conditions have the potential to hinder students in developing creative reasoning strategies because most of their cognitive capacity has been used to understand the ineffective task presentation.

Several previous studies have examined strategies that can reduce extraneous cognitive load. These studies show that more structured teaching strategies, better use of visualization, and the use of relevant examples can help reduce this load (Ayres et al., 2021; Gupta & Zheng, 2020; Kalyuga & Plass, 2017). However, most of these studies still focus on secondary and higher education levels, and have not specifically explored the impact of extraneous cognitive load on elementary students' creative reasoning in learning geometry. In addition, the relationship between learning designs that cause extraneous cognitive load and mathematical creative thinking performance in the context of primary education is still relatively under-researched. This creates a research gap, because there are not many studies that connect how extraneous cognitive load directly affects creativity in solving math problems in elementary school students. Creativity in mathematics cannot arise from repetitive practice alone, but through reasoning activities that demand understanding, new strategies, and logical justification (Lithner, 2017; Norqvist et al., 2019; Palinussa et al., 2021).

Therefore, this study has novelty because it specifically examines the relationship between extraneous cognitive load and mathematical creative reasoning of elementary school students in the context of solving geometry problems. This study not only aims to map the level of extraneous cognitive load experienced by students, but also analyze how the load affects the way students develop creative problem-solving strategies. Theoretically, this research contributes to the development of Cognitive Load Theory in the context of learning at the elementary level. Practically, the results of this study are expected to be the basis of recommendations for teachers in designing mathematics learning, especially geometry that has minimal extraneous cognitive load and is able to optimally encourage students' mathematical creativity. With this approach, basic education is not only a place to instill basic mathematical concepts, but also as a foundation for developing creative thinking in facing future challenges.

METHODS

This research used a qualitative approach with a case study design (Baxter & Jack, 2015; Crowe et al., 2011; Yin, 2003). This approach aims to explore in depth the relationship between extraneous cognitive load and students' mathematical creative reasoning ability in the context of geometry learning in elementary school. This approach is in accordance with the characteristics of case studies according to Creswell, (2018), which is to understand phenomena contextually through various data sources.

The research subjects consisted of 27 grade 6 students in an Indonesian elementary school who had studied the topic of building spaces. The data sources in this study are the students as the main informants, while the class teacher acts as a supporting informant to provide additional context to the implementation of learning and classroom management. The research instruments include: i) extraneous cognitive load questionnaire developed based on Cognitive Load theory by Sweller et al., (2019); ii) mathematical creative reasoning test with mathematical foundation, plausibility, and novelty indicators Lithner, (2015); and iii) semi-structured interview guidelines to explore students' thinking strategies. The extraneous cognitive load test developed questionnaire statements which included: split attention situation; redundancy situation; transiency situation; advanced learner situation; and inadequate prior knowledge situation, adopted from (Van Merriënboer & Sweller, 2005) and used a subjective rating scale adapted from Korbach et al., (2018) and categorized as presented in table 1 below.

Table 1. Student Extraneous Cognitive Load Categories

No	Range	Category
1	x > mean + SD	Low
2	mean - SD ≤ x ≤ mean + SD	Medium
3	x < mean - SD	High

Data analysis techniques were carried out qualitatively through descriptive and thematic analysis. Questionnaire results were analyzed to group students into low, medium, and high cognitive load categories. Tests were analyzed based on creative reasoning indicators. Interview data were analyzed through the stages of reduction, categorization, and conclusion drawing (Miles et al., 2014). Data triangulation was conducted to ensure the validity of the findings.

RESULT AND DISCUSSION

This study aims to examine the effect of extraneous cognitive load on creative reasoning ability of elementary school students in solving geometry problems. Creative reasoning was analyzed based on three main indicators, namely mathematical foundation (ability to understand and organize basic information mathematically), plausibility (ability to explain the logical reasons for the strategies used), and novelty (ability to produce unique or unusual approaches) (Lithner, 2015). The materials used in the test were adapted to the elementary school curriculum, covering concrete contexts such as calculating the volume of a toy box, combining several water containers, and estimating the size of objects from simple building pieces. On the other hand, extraneous cognitive load was measured based on five indicators, namely: split attention (difficulty students focus due to the presentation of fragmented information or the environment is not conducive), redundancy (information presented is too much or multiple so that it exceeds students' working capacity), transiency (delivery of material or working on questions that are too fast and rushed), advanced learner (teacher strategy or language use is not in accordance with students' abilities), and inadequate prior knowledge (students do not have sufficient prior knowledge to process new information) (Sweller et al., 2019). The following discussion is organized to show the relationship between extraneous cognitive load categories, creative reasoning ability, and how they interact with each other in the process of solving contextual geometry problems of elementary school learning.

The questionnaire results show that most students experience extraneous cognitive load at a moderate level. The distribution of this data provides the basis that the majority of students are in a cognitive condition that is not too light, but also has not experienced severe impairment. This can be seen in table 2 below.

Table 2. Distribution of Student Extraneous Cognitive Load Categories

Category	Range	Number of Students	% Percentage
Low	x > 72,62	4	14,81
Medium	53,27 ≤ x ≤ 72,69	21	77,78
High	x < 53,27	2	7,41
Total		27	100

To clarify the trend of differences in extraneous cognitive load scores between categories, Figure 1 presents a visualization of the average score obtained by students based on the questionnaire results.

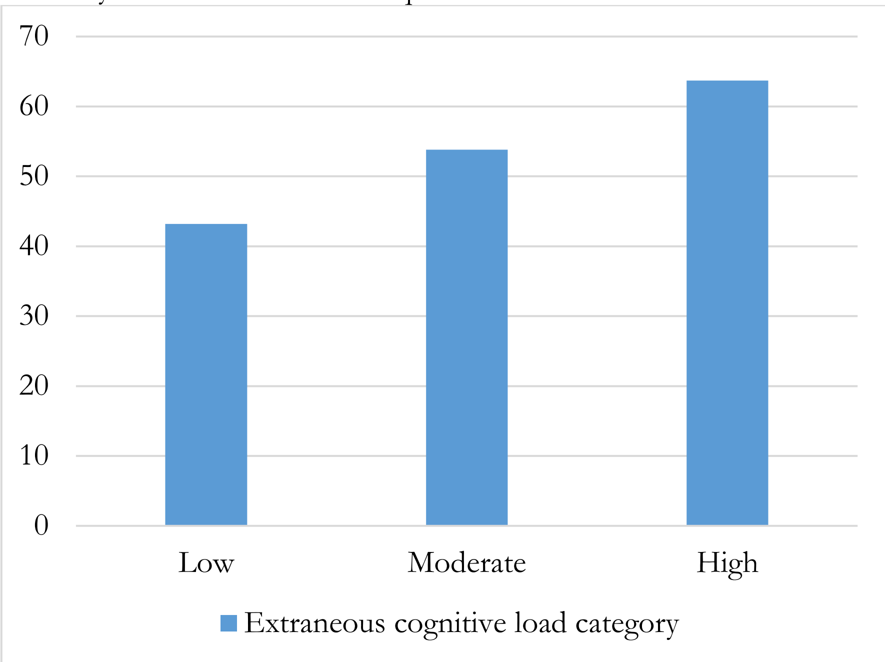

Fig 1. Average Student Extraneous Cognitive Load Score per Category

Figure 1 shows the stark differences between categories. Students in the high load category had an average score of 63.7, significantly higher than students in the medium (53.8) and low (43.2) categories. This difference reflects that the higher the students' perception of extraneous cognitive load, the greater the mental disturbance they experience when working on problems. This condition is an early indicator that learning has not fully succeeded in minimizing the burden of aspects of information presentation, problem structure, and visual media used in geometry tasks.

These initial findings were then further examined based on indicators of extraneous cognitive load. The data showed that in the high extraneous cognitive load category, the lowest scores were consistently found in the split attention and inadequate prior knowledge indicators. This means that students have difficulty in focusing attention when information is presented separately or when they do not have sufficient prior knowledge to relate new information. In contrast, students with low extraneous cognitive load did not experience significant impairment in these five indicators.

This condition has a direct impact on the quality of students' mathematical creative reasoning. To clarify this relationship, further analysis focused on how the different levels of extraneous cognitive load affect the quality of students' creative reasoning in answering geometry problems. Students with low extraneous cognitive load were able to organize mathematical information completely and logically (mathematical foundation), explain the reasoning behind their strategies (plausibility), and modify or create unique approaches to problems (novelty). This strong negative correlation makes it clear that the presence of irrelevant instructional load is a serious obstacle in activating students' creative thinking potential.

This difference in ability is more evident when analyzed based on the context of each problem. In the first problem, students were asked to calculate the volume of a toy box made of cardboard pieces. This problem measures spatial visualization skills and the ability to relate shapes to the concept of block volume. Students with low extraneous cognitive load were able to recognize the shape of the net, determine the length, width, and height correctly, and apply the volume formula correctly. In contrast, students with moderate extraneous cognitive load often mistakenly determine the side that acts as height or just copy the formula without understanding the steps. Students with high load were unable to start the solution because they did not understand the shape representation, which was caused by unprepared prior knowledge and distracted attention due to undirected drawings.

The second problem tested students' ability to calculate the volume of water from two block containers combined. This context encourages students to break down the shape into simple parts and calculate the volume of each part. The low extraneous cognitive load group showed a coherent solution strategy and could explain the reason for using the formula. The medium extraneous cognitive group experienced conceptual errors and mistakenly assumed certain sides as the base. The high extraneous cognitive group again failed to understand the relationship between shape and numerical information, and even considered the problem too complicated because it was long and contained too many numbers. This condition illustrates the effect of high split attention and redundancy load.

The last problem provides a realistic context in the form of estimating the volume of a small irregularly shaped pool. This problem is open-ended and requires flexibility of thinking and remodeling the shape into two blocks. Norqvist et al., (2019) emphasized that creative reasoning demands the creation of new strategies such as the request in this problem. Students with low extraneous cognitive load were able to construct logical approaches and explain their reasons for dividing the shapes. Some students from the medium extraneous cognitive category started correctly, but did not complete the calculation until the end. While students with high extraneous cognitive load did not write anything other than not knowing how to do it, which indicates low mathematical foundation as well as novelty.

To enrich the understanding of students' thought process, in-depth interviews were conducted. The results showed that students with low extraneous cognitive load not only answered correctly, but could also explain their strategies in their own language. In contrast, students with high extraneous cognitive load often stated that they did not understand what the problem asked for, did not know the first step to take, and felt they had never seen a problem like this before. These differences in perception and reflection mark differences in the quality of creative reasoning between groups. Key excerpts from the interviews can be seen in the following table.

Table 3. Interview Excerpts by Extraneous Cognitive Load Category

Theme	Extraneous Cognitive Load Category	Interview Excerpt
Understanding the Problem	Low	"I cut the box into pieces, then I matched the measurements to the formula length times width times height"
Unclear Strategy	Medium	"I was confused about which side was the base. So I just used the normal method that I have been taught"
External Interference	High	"The problem makes me confused and the time is also fast, I think for a long

Theme	Extraneous Cognitive Load Category	Interview Excerpt
		time because I don't understand how to read it”

In addition, the interviews revealed the presence of transiency and redundancy burdens that interfered with students' focus in understanding the problem, especially from the medium and high categories. One student mentioned that he had to read the problem more than twice because there were too many numbers and information going back and forth. Under these conditions, students' working memory is filled with efforts to filter information, not to develop a solution strategy, thus inhibiting the emergence of creative thinking. Students from the low extraneous cognitive load category were more focused, able to take the essence of the problem, and simplify the information in their minds to develop effective solutions.

This finding reinforces that creative reasoning requires optimal cognitive working capacity. High extraneous cognitive load occupies students' thinking space, making them fail to understand information, choose strategies, and formulate creative solutions. Based on the Cognitive Load theory (Sweller et al., 2019), this occurs because the design of instructions or media is not in accordance with the cognitive capacity of learners, thus disrupting the effectiveness of learning. This research is in line with the findings of (Jonsson et al., 2022; Lithner, 2017), who emphasized that creativity in mathematics does not arise from mechanistic procedures, but from students' ability to construct meaning, develop strategies, and explain them logically. If the learning conditions are not well designed, then students will not reach the expected level of creative thinking, even though they have the potential.

Thus, this study thoroughly answered the set objectives. Creative reasoning in elementary school students is shown to be strongly influenced by the level of extraneous cognitive load. The practical implication is the need for elementary school teachers to design structured geometry learning, use appropriate visual media, and simplify instructions so as not to increase students' mental load. This is reinforced by the statement of Dwirahayu et al., (2021) that the development of structured visual tasks is important to help elementary school students build reasoning strategies. In addition, Melhuish et al., (2020) state that students' success in producing original solutions is strongly influenced by the extent to which they are given space to explore and reflect on strategies.

CONCLUSION

This study shows that extraneous cognitive load has a significant effect on the mathematical creative reasoning ability of elementary school students in solving geometry problems. Students with low extraneous cognitive load tend to be able to understand information, develop logical strategies, and produce original solutions. Conversely, students with high extraneous cognitive load have difficulty in understanding the problem, strategizing, and developing answers creatively. Indicators such as split attention, redundancy, and inadequate prior knowledge become dominant obstacles, especially when problems are presented with visuals or less structured instructions. Therefore, teachers need to design geometry lessons that are more focused, simplify instructions, and adjust the presentation to the cognitive capacity of students.

This study recommends that further studies develop learning designs that explicitly reduce extraneous cognitive load, as well as expand the material context and education level to strengthen the findings.

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