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Adding Self-Explanation When Learning Goal-Free Problems Could Be Beneficial

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ABSTRACT

A goal-free problem is a strategy for presenting a geometrical problem by removing its final goal, in order to discourage students from using a means-ends analysis. The purpose of this research was to examine whether adding self-explanation instruction could improve the effectiveness of goal-free problems with regard to students' problem-solving ability and cognitive load. Using geometry (the relationships among angles) as part of the national curriculum, a quasi-experimental study was conducted. A post-test-only control group design, comparing learning with and without self-explanation, involved fifty-two seventh-graders from two parallel classrooms in a junior high school in Central Java, Indonesia, with prior math test scores used as a covariate. The covariate did not show a significant linear relationship with the outcome, indicating that both experimental groups were randomly assigned and had the same level of prior knowledge before the experiment was conducted. The overall evidence indicated that, with or without self-explanation, both groups of students who were given goal-free problems did not differ significantly in problem-solving ability. However, there was a significant difference in cognitive load. Learning goal-free problems with self-explanation could be more effective, since this strategy leads to a lower cognitive load than learning without self-explanation. This study suggests that self-explanation instruction may lower extraneous cognitive load and improve learning.

Goal-free problems merupakan strategi untuk menyajikan masalah geometri dengan menghilangkan tujuan akhir guna mencegah siswa menggunakan *means-end analysis.* Tujuan dari penelitian ini yaitu untuk menguji apakah penambahan *instruksi self-explanation* dapat meningkatkan efektivitas goal free problems terkait kemampuan pemecahan masalah dan cognitive load siswa. Dengan menggunakan materi geometri (hubungan antar sudut) yang merupakan bagian dari kurikulum nasional, studi kuasi-eksperimental telah dilakukan. *Post-test-only group design*, yang membandingkan pembelajaran tanpa dan dengan *self-explanation*, melibatkan 52 siswa kelas tujuh dari dua kelas paralel di sebuah sekolah menengah pertama di Jawa Tengah, Indonesia, dengan skor tes matematika sebelumnya digunakan sebagai kovariat. Kovariat tersebut tidak menunjukkan hubungan linier yang signifikan dengan hasil penelitian, yang mengindikasikan bahwa kedua kelompok eksperimen telah dialokasikan secara acak dan memiliki tingkat pengetahuan awal yang sama sebelum eksperimen dilakukan. Bukti secara keseluruhan menunjukkan bahwa, tanpa atau dengan *self-explanation*, kedua kelompok siswa yang diberikan masalah goal-free problems tidak memiliki perbedaan yang signifikan dalam kemampuan pemecahan masalah. Namun, terdapat perbedaan yang signifikan dalam *cognitive load*. Pembelajaran *goal-free problems* dengan *self-explanation* terbukti lebih efektif, karena strategi ini menghasilkan beban kognitif yang lebih rendah dibandingkan pembelajaran tanpa *self-explanation*. Penelitian ini menyarankan bahwa instruksi *self-explanation* dapat menurunkan *extraneous cognitive load* dan meningkatkan hasil belajar.

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INTRODUCTION

Mathematics learning is essentially characterized by problem-solving activity; therefore, presenting problems clearly is critical when designing instruction. Santos-Trigo (2020) defines problem solving as "the systematic study of what the process of formulating and solving problems entails and the ways to structure problem-solving approaches to learn mathematics." Based on their knowledge and problem-solving experience, students can determine the right strategy to solve the problem. Irwansyah & Retnowati (2019) claimed that students tend to find it easier to solve problems if they have prior knowledge. However, students who face new problems but have limited prior knowledge will find it more difficult to solve them.

Ability to learn problem-solving ability differs based on prior knowledge. According to Joseph (2011), students' difficulties in solving mathematics problems are caused by the lack of problem understanding, the lack of knowledge of problem-solving strategies, and an inability to translate problems into mathematical form and to use mathematics correctly. Knowledge base assists students to understand given information and context in problem solving.

Polya (1973) identifies four steps in solving problems: understanding the problem, planning for problem solving, carrying out the plan, and re-examining the procedure and the results of the solution. In carrying out the plan, students are required to solve problems based on their background knowledge. Goal-free problems facilitate students in relating one variable to another as a whole (Sweller et al., 2011). By doing so, students identify more unknown variables and are able to learn more thoroughly. Polya also suggested that problem solving should be followed by checking the resulting solution steps. When a self-explanation task is given, students may elaborate on their problem solving and hence understand the material better and more meaningfully.

Cognitive load theory used principles of human cognitive architecture in designing instructions. The three components of memory that correspond to the human cognitive architecture are sensory memory, working memory, and long-term memory (Sweller, Ayres, & Kalyuga, 2011). Human cognitive processes will occur consciously in working memory. Human working memory has a finite capacity and duration (Sweller et al., 2011). Therefore, material should be provided in stages so that the information process is not overburdened.

Sweller et al. (2011) state that working memory is affected by three important factors, namely intrinsic cognitive load, extraneous cognitive load, and germane cognitive load. The difficulty of the topic determines the intrinsic cognitive load, so the material must be presented effectively. Meanwhile, the way the learning material is presented determines the extraneous cognitive load (Sweller, 2010).

Poor material presentation, non-constructive material delivery, and uninteresting or complicated learning media will eventually make it difficult for students to learn. Extraneous cognitive load can be reduced through materials that are well-designed, organized, and presented, with messages delivered in an instructional manner. Meanwhile, when both intrinsic and extraneous cognitive load are adequately managed, germane cognitive load appears (Sweller et al., 2011), because students' ability to comprehend and construct new content is linked to their cognitive load. Thus, it is preferable to decrease extraneous cognitive load in learning activities (Sweller, 2010).

Another well-documented source of unnecessary cognitive burden is the split-attention effect, which arises when a learner must mentally switch between different but related information formats, such as text and diagrams that are physically separated from one another (Ayres & Sweller, 2005; Sweller et al., 2011). In such split-source materials, learners must hold information from one source in working memory while searching for and interpreting corresponding information in another location, and then mentally integrate the two before learning can proceed (Tarmizi & Sweller, 1988). This constant shifting and searching does not directly support schema construction; instead, it consumes limited working memory resources that would otherwise be available for understanding the content itself, thereby generating extraneous cognitive load (Cierniak, Scheiter, & Gerjets, 2009; Ward & Sweller, 1990). Consistent with this view, research indicates that poorly designed instructional materials which trigger split-attention can hinder students' performance (Ayres & Sweller, 2005; Chandler & Sweller, 1991; Mayer & Anderson, 1991; Mayer & Sims, 1994).

Within cognitive load theory, several instructional approaches have been proposed to reduce split-attention effects, particularly spatial integration, signaling, and accounting for learners' prior knowledge. Although these approaches differ in their implementation, they share the common objective of minimizing unnecessary cognitive processing so that learners can allocate more working memory resources to meaningful learning.

One of the most extensively studied approaches is spatial integration, which is closely associated with the spatial contiguity principle in multimedia learning research: learning improves when related textual and visual information are presented in close physical proximity rather than in separate locations (Mayer & Fiorella, 2014). In practice, this is commonly implemented by embedding explanatory text directly within a diagram rather than presenting it separately (Chandler & Sweller, 1991; Moreno & Mayer, 1999; Sweller & Chandler, 1994; Tindall-Ford et al., 2015). By reducing the need for learners to search for and coordinate separate information sources, spatial integration decreases unnecessary cognitive load, and studies have demonstrated its effectiveness across domains including mathematics and science, in both paper-based and digital learning environments (Tarmizi & Sweller, 1988; Chandler & Sweller, 1991; Moreno & Mayer, 1999; Tindall-Ford et al., 2015).

Split-attention effects may also be reduced through signaling, which does not change the physical placement of instructional materials but instead guides learners' attention toward relevant information using visual cues such as bolding, color, arrows, or highlighting (Jeung, Chandler, & Sweller, 1997; Mautone & Mayer, 2001; Mayer & Fiorella, 2014). Signaling helps learners identify relationships between conceptually connected elements, reducing the cognitive effort required to locate and organize information mentally.

The effectiveness of these strategies also depends on learners' prior knowledge, which influences how learners process and benefit from a given instructional design (Cooper, Sidney, & Alibali, 2018; Kalyuga, Ayres, Chandler, & Sweller, 2003; Richter, Scheiter, & Eitel, 2016). Learners with sufficient background knowledge are generally better able to interpret integrated or signaled information, whereas learners with limited prior knowledge may still struggle to relate multiple sources of information to one another.

More recent perspectives suggest that the split-attention effect is associated not only with extraneous cognitive load but also with germane cognitive load. In split-source formats, working memory resources are heavily consumed by the mental-integration process, leaving fewer resources available for schema construction, whereas integrated formats free up cognitive resources for this purpose (Kester, Kirschner, & Van Merriënboer, 2005). Tabbers, Martens, & Van Merriënboer (2000) similarly reported a reciprocal relationship between the two types of load: integrated formats reduced extraneous load while fostering germane load, whereas split-source formats increased extraneous demands and limited the resources available for meaningful learning.

Empirical studies provide further support for this account. Cierniak, Scheiter, and Gerjets (2009) compared integrated and split-source formats in complex physiological learning and found that, although secondary-task measures showed no overall difference in cognitive load between conditions, learners in the integrated condition outperformed those in the split-source condition on terminology, labeling, and factual-knowledge tasks, while subjective ratings showed simultaneously lower extraneous load and higher germane load, supporting the germane-load explanation of the split-attention effect. However, the effect is not always found: Zhang, de Koning, and Paas (2024) examined whether presentation size (large vs. small) moderated the split-attention effect on a computer interface and found no significant effects of format or size on retention, comprehension, or extraneous load, suggesting that the effect may be sensitive to presentation medium. Individual differences also appear to matter: Fenesi, Kramer, and Kim (2016) found that learners with lower working-memory capacity were selectively impaired by split-attention formats (audio narration combined with on-screen text and images) on applied comprehension questions, while learners with higher working-memory capacity were largely unaffected; removing the redundant on-screen text eliminated this gap.

Goal-free problems, discussed next, represent another strategy grounded in cognitive load theory for reducing extraneous cognitive load, in this case by removing the need for means-ends search, rather than by addressing the physical layout of instructional materials.

Goal-free problems are one strategy for reducing extraneous cognitive load. According to Ayres (1993), goal-free problems are useful for enhancing students' problem-solving ability. This strategy replaces problems that have a specific aim with problems that have no specific goal, enabling novice learners to solve problems using fewer means-ends analysis strategies. For example, in geometry, a problem with a specified aim (a goal-given problem) is phrased as "find the value of x," where x denotes an angle. When the same problem is presented as goal-free, students do not merely identify the value of x; instead, they calculate the sizes of all the unknown angles. The question then becomes "determine all the sizes of the unknown angles."

By using goal-free problems, students learn to acquire and build knowledge from known information and can think logically about the problems offered, rather than focusing only on applying the mathematical principles they are learning. Furthermore, students become accustomed to solving problems by working forward, a strategy that helps them acquire more material while reducing cognitive burden. This strategy is the polar opposite of the means-ends analysis strategy and can also improve students' problem-solving abilities.

Many studies have shown that goal-free problems are effective for learning mathematics, including a study by Purnama & Retnowati (2020), which found that goal-free problems produced significantly higher scores but a lower cognitive load on retention and transfer tests compared with goal-given problems. Individual learning scores were also found to be significantly higher than scores achieved through collaborative learning. The study concluded that goal-free problems are effective for both individual and collaborative learning, since no interaction effect was found. The research was conducted at a public junior high school in Kebumen, Central Java, using WhatsApp for online learning.

Because individual learning is effective when applied to goal-free problems, it is used here to learn new content, with self-explanation as the strategy for implementing individual learning. Individual learning is a metacognitive method that gives students instructions to help them regulate their own cognitive abilities. Metacognition is a deliberate process of reflecting on what has already been learned (Moritz & Lysaker, 2018). According to McNamara & Magliano (2009), self-explanation is the process of explaining text to oneself, either orally or in writing, and is generally thought to modify one’s understanding during the learning process.

From a cognitive load perspective, self-explanation challenges students to form connections between elements of examples and prior knowledge (Sweller et al., 2011). This process requires sufficient working memory resources. Working memory will not function well for students with poor prior knowledge, since much of the load falls on working memory itself, whereas students with strong prior knowledge will find self-explanation easier because they can draw on knowledge already stored in long-term memory, allowing working memory to function properly (Sweller et al., 2011).

A number of earlier studies have shown that self-explanation helps with problem solving. According to Chi, Bassok, Lewis, et al. (1989), applying self-explanation can increase students' problem-solving abilities. Self-explanation can also build and integrate newly learned content with prior knowledge (Chi, de Leeuw, Chiu, et al., 1994).

Kwon, Kumalasari, and Howland (2011) found that self-explanation can help students understand new content even when they are prompted to do so. This is because students with limited prior knowledge in understanding new material and solving problems still benefit from self-explanation, which also generates a minimal cognitive load. This strategy can teach students to try to understand a concept in a lesson on their own, making them more self-sufficient in solving problems because they ask and answer questions of themselves.

Combining goal-free problems with the self-explanation strategy requires students to explain the problem to themselves in their own words and to ask themselves how the solution could be reached. This combination is expected to improve students' problem-solving ability and make the learning process more meaningful. Hence, in this study, the combination of goal-free problems and self-explanation was assumed to be more effective, particularly for learning geometry.

Students' problem-solving ability and cognitive load can be used to determine the effectiveness of combining goal-free problems with self-explanation strategies. This study was undertaken to investigate whether adding a self-explanation strategy to goal-free problem-based mathematics learning would be beneficial, particularly for improving problem-solving ability.

METHODS

Research design and participant

This study used a quasi-experimental research design comprising two experimental groups: goal-free problems with self-explanation, and goal-free problems without self-explanation. The participating public junior high school in Central Java, Indonesia, had four parallel seventh-grade classes that used the same curriculum and were taught by the same mathematics teacher. Two classes were randomly selected to take part in this experiment. The first class had 32 students, but only 27 students turned up and assigned to the first experimental group, studying goal-free problems with self-explanation instruction. The second class had 32 students, but 25 students showed up and allocated to the second experimental group, who were given goal-free problems without self-explanation instruction. The teacher confirmed that all students had studied lines and angles, but had not yet learned the relationships among angles. The teacher also provided the students' mid-semester exam scores for both classes: for the first class, $M = 67.52$, $SD = 12.44$; for the second class, $M = 64.00$, $SD = 15.88$. A t-test yielded $t(50) = 0.893$, $p > 0.05$, indicating that the level of mathematics ability between the two classes was not significantly different.

Material

At the time the intervention was run, the participants were considered novices with respect to the problem-solving content. To satisfy this criterion, the researchers consulted the teacher about what students had already learned based on the national curriculum used in the school. It was agreed that the theorems on the relationships among angles formed by parallel lines and a transversal had not yet been taught.

For the self-explanation instruction, this question was given together with each goal-free problem to be solved: “Find and explain the angle theorem in the picture above.” Students were expected to write their explanation in the space provided. Figure 1 shows the goal-free problem learning design with self-explanation.

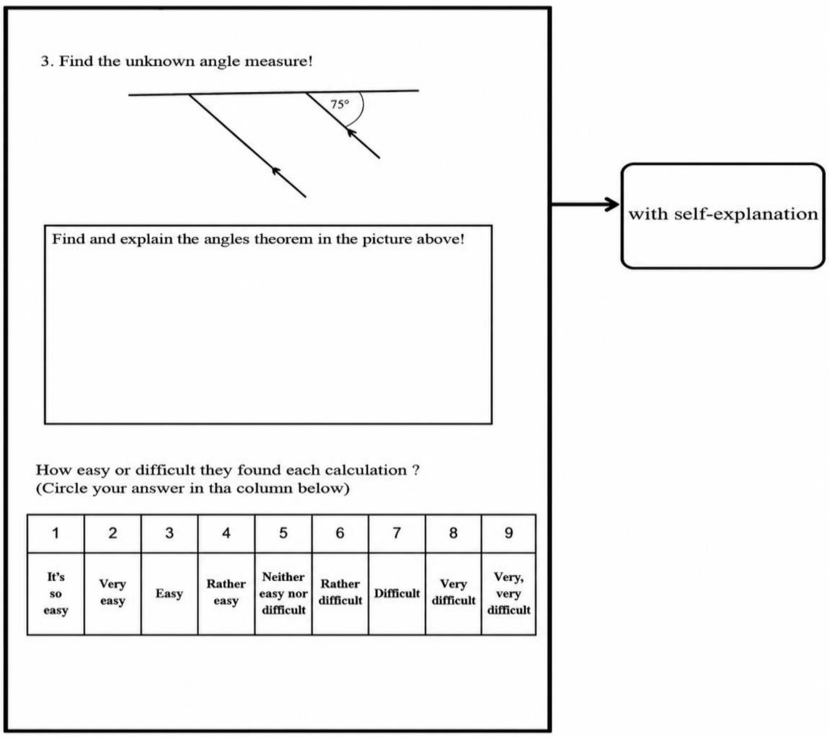

Figure 1. Goal-free problems with self-explanation

Research Procedure

This research was conducted in several phases (Figure 2). The introduction phase began with the activation (recalling) of prior knowledge, conducted over 7 minutes, followed by the introduction of new material, conducted over 25 minutes. Students were introduced to and taught the theorems on the relationships among angles by being shown pictures of angle compositions. At the end of this phase, they were also given a goal-free problem-solving task to train them in what to expect when solving a goal-free problem, since this type of problem presentation had never been encountered by the students before the experiment.

The following phase was the acquisition phase, conducted on the second day, in accordance with the experimental grouping. The first group solved goal-free problems with self-explanation, while the second group solved goal-free problems without self-explanation instruction. This phase began with an opening stage and ended with a closing stage; overall, it lasted 60 minutes. The final phase was the assessment, or post-test, of problem-solving ability, consisting of eight problems to be completed within a maximum of 80 minutes.

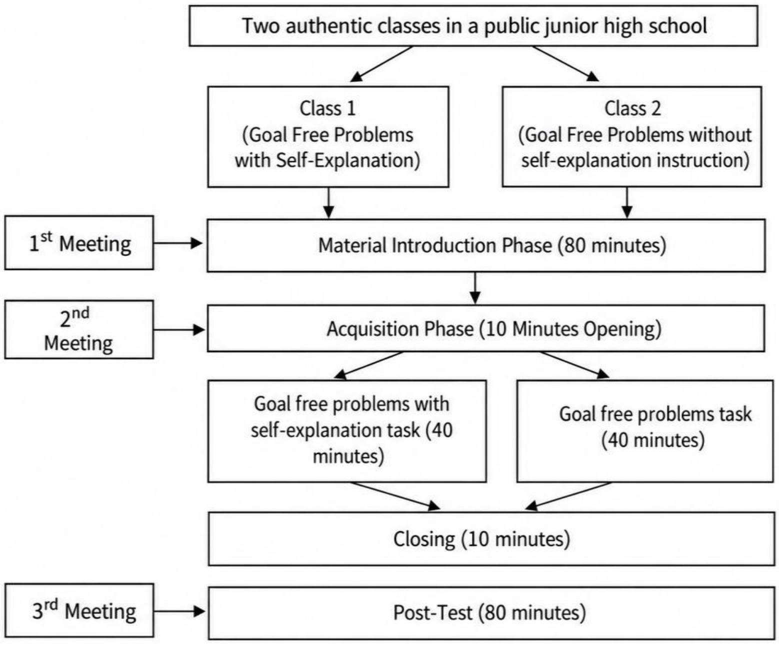

Figure 2. Research Procedure Diagram

Measures

The post-test consisted of descriptive problem-solving questions. A score of 1 was given for each correct solution and 0 for each incorrect solution. The cognitive load question was the same as that used by Retnowati, Ayres, & Sweller (2017), which used a nine-point Likert scale. Cognitive load was measured in the post-test by asking participants to rate their level of difficulty for each test problem. The rating for each subject was the averaged score across problems.

RESULTS

The description of the data provides an overview of students' problem-solving ability and cognitive load test results. The results of the analysis are presented in Table 1.

Table 1. Descriptive Analysis of Post-test Data and Cognitive Load Results

Description	With Self-Explanation n = 27	Without self-explanation n = 25
M	80,093	75,00
SD	12,262	15,415
Max	100	100
Min	50	43.75
M	4,730	5,228
SD	0,750	0,903
Max	5,9	6,5
Min	3,1	3,3

The normality tests in this study used the Kolmogorov-Smirnov test with a significance level of 0.05, presented in Table 2.

Table 2. The Normality Test on Problem Solving Ability Test Result

Condition	Normality Test	*P-value*	Conclusion
Problem Solving			
With Self-Explanation	Kolmogorov-Smirnov	0,054	normally distributed
Without Self-Explanation	Kolmogorov-Smirnov	0,200	normally distributed
Cognitive Load			
With SE	Kolmogorov-Smirnov	0,200	normally distributed
Without SE	Kolmogorov-Smirnov	0,055	normally distributed

The following t-test and Cohen's d results were then calculated.

After the prerequisite tests were met, the next step was to conduct the hypothesis tests. Hypothesis testing was done using a t-test with a significance level of 0.05. The purpose of the first hypothesis test was to examine whether there was a significant difference in effectiveness between goal-free problems learning with self-explanation and goal-free problems learning alone, viewed from students' problem-solving abilities. The mean problem-solving ability score for goal-free problems learning with self-explanation (M=80.093; SD=12.262) is higher than for goal-free problems learning alone (M=75.000; SD=15.415). Table 3 below shows the output of the t-test.

Table 3. Pair Comparison Test Results

Dependent variables	t	df	Std	p-value	Cohen's d
Problem Solving Score	1,3233	50	3,838	0,1918	0,365
Cognitive Load	2,1702	50	0,230	0,0348	0,599

Based on the t-test with the mid-term test score as the dependent variable, the result was $sig = 0{,}379$. There was no significant difference between the mid-term test scores of the two groups. Based on the t-test with problem-solving ability as the dependent variable, the result was sig = 0.1918. There is no significant difference between goal-free problems learning with self-explanation and goal-free problems learning alone. This means that goal-free problems learning with self-explanation is not significantly better than goal-free problems learning alone in terms of students' problem-solving abilities; the type of learning strategy has only a low effect (Cohen's d = 0.365) on students' problem-solving abilities.

The second hypothesis test aimed to determine whether there is a difference in effectiveness between goal-free problems learning with self-explanation and goal-free problems learning alone, viewed from students' cognitive load. The average cognitive load for goal-free problems learning with self-explanation ($M = 4.7296$; $SD = 0.7503$) is lower than for goal-free problems learning alone ($M = 5.228$; $SD = 0.9035$).

Based on the t-test with cognitive load as the dependent variable, the result was $sig = 0.0348$. This means that there is a significant difference between goal-free problems learning with self-explanation and goal-free problems learning alone in terms of students' cognitive load. Differences in learning method affect students' cognitive load: the use of the self-explanation technique has a medium effect on the goal-free problems approach (Cohen's d = 0.599). In addition, goal-free problems learning with self-explanation is more effective than goal-free problems learning alone in reducing students' cognitive load.

DISCUSSION

The results of the first hypothesis test related to students' problem-solving abilities show that there is no significant difference between goal-free problems learning with self-explanation and goal-free problems learning alone. Although the average problem-solving ability score for goal-free problems learning with self-explanation appears higher ($\underline{x}$ = 80.0926) than for goal-free problems learning alone ($\underline{x}$ = 75.00), this difference was not statistically significant. In other words, the average score of the group using goal-free problems with self-explanation was not significantly higher than the score of the group using goal-free problems alone.

Essentially, goal-free problems relate to problem solving by eliminating the final goal of a mathematical problem. Goal-free problems are very helpful for students in understanding the material and the relationships among variables, as they allow students to construct problems based on known information (Sweller et al., 2011). Goal-free problems can minimize extraneous cognitive load, and as a result, working memory functions more optimally in constructing knowledge. Ayres (1993) argues that goal-free problems are effective for improving problem-solving ability.

Self-explanation is a teaching strategy in which students explain material to themselves, both orally and in writing, and is generally assumed to modify understanding during the learning process (McNamara & Magliano, 2009). In the self-explanation strategy, students not only memorize the material but also understand what is being studied. In this learning process, self-explanation actively involves students in understanding a worked example through the explanations provided, ensuring that understanding the material becomes a meaningful process in which students can verify the correctness of their solution against the new material presented. This involves cognitive processes such as analyzing, explaining, and verifying, which are higher-order cognitive processes than simply remembering (Anderson et al., 2001).

Goal-free problems learning without self-explanation can also improve problem-solving ability. This is in line with research by Ayres (1993), who found that goal-free problems are effective for improving students' problem-solving ability. Learning with goal-free problems, whether combined with self-explanation or not, improves problem-solving skills for the relationships among angles.

The results of the second hypothesis test on cognitive load show a difference in effectiveness between goal-free problems learning with self-explanation and goal-free problems learning alone: goal-free problems learning with self-explanation is better than goal-free problems learning alone. This means that the self-explanation strategy lowers students' cognitive load when solving problems on the relationships among angles. This is in line with cognitive load theory as described by Sweller (1988), who argued that self-explanation can provide students with a lower cognitive load in problem solving because it helps them focus their cognitive resources, avoid splitting their attention, and limit activities that do not directly support learning. Problem solving without this support is considered a high-cognitive-load activity, since students must search extensively for suitable operators, introduce appropriate constraints, and determine solution paths using prior knowledge.

Goal-free problems learning is a method that can minimize cognitive load, in line with Ayres (1993), who found the goal-free problems strategy to be effective for minimizing students' cognitive load. Combining goal-free problems with self-explanation can minimize cognitive load further, since both strategies work toward the same end. It can therefore be concluded that the findings of this study support the hypothesis that goal-free problems learning with self-explanation significantly minimizes students' cognitive load. Goal-free problems are a strategy for minimizing extraneous cognitive load, which allows working memory to work more optimally in constructing knowledge. This facilitates the storage of students' knowledge in long-term memory. By learning with goal-free problems, students can build and develop their knowledge by relating the information provided to knowledge they already possess. This helps students understand new material thoroughly and can improve their problem-solving abilities.

The self-explanation strategy enables students to deepen their knowledge by explaining the reasons or basis for each step presented (Chi et al., 1989). Therefore, students gain a more thorough understanding of the material (Tekeng, 2015). Once students understand the material thoroughly, they can apply its concepts to a new problem. This self-explanation strategy is carried out individually; since the geometry of angle relationships is complex material, self-explanation allows students to process it themselves, understand what they have learned, and process all information independently. By doing so, students become more focused on understanding the material and solving problems (Retnowati, Ayres, & Sweller, 2010). Self-explanation is a metacognitive strategy in which students explain learning material to themselves, encouraging them to understand it thoroughly. Applying metacognitive strategies might help students improve their thinking processes and guides them to plan, monitor, and evaluate their own work.

CONCLUSION

It can be concluded that, with or without self-explanation, both groups of students who were given goal-free problems did not differ significantly in problem-solving ability. However, there was a significant difference in cognitive load. Learning goal-free problems with self-explanation may be more effective, since this strategy leads to a lower cognitive load than learning without self-explanation. This study suggests that self-explanation instruction may lower extraneous cognitive load and improve learning. Future research should examine whether specific self-explanation guidance influences the effectiveness of the instruction.

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