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EXPLORING THE ROLE OF EXAMPLE PROBLEM-BASED LEARNING IN MANAGING STUDENTS' COGNITIVE LOAD DURING COMPLEX MATHEMATICAL PROBLEM SOLVING

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ABSTRACT

This study aims to validate the effect of EPBL in reducing students' cognitive load in solving complex mathematical problems. It also examines the impact of EPBL implementation on students learning process. This study uses a mixed-method approach with a concurrent triangulation design. The subjects of this study were one 8th-grade class at SMP Negeri 14 Kota Serang, consisting of 36 students. Quantitative data were analyzed using paired t-test statistics, while qualitative data obtained through semi-structured interviews were analyzed using thematic analysis. The results showed that the implementation of EPBL significantly improved students' mathematical problem-solving abilities. The average score increased from 47.50 in the pretest to 76.39 in the posttest, with an effect size of 1.011, which is considered large. The results also showed a significant decrease in students' cognitive load, with the average score decreasing from 50.25 to 17.00 and an effect size of 2.269, which is considered very large. Qualitative findings support these results through two main themes: ease of understanding the material and learning comfort. Students stated that the use of worked examples helped them understand concepts and problem-solving procedures more effectively, while the structured learning process created a more comfortable learning atmosphere. The findings of this study indicate that EPBL contributes to improving mathematical problem-solving skills while helping reduce students' cognitive load in solving complex mathematical problems. This study provides empirical evidence regarding the effectiveness of integrating worked examples and problem-solving activities as a mathematics learning strategy that supports students' cognitive load management.

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1. INTRODUCTION

Mathematics is a branch of science that plays an important role in developing critical thinking and problem-solving skills. These skills are essential for every student to possess. According to Maulyda (2020), the main objective of students learning mathematics is to develop students who have analytical, critical, creative, logical, and systematic thinking skills. In the field of education, students are not only required to understand basic mathematical concepts but also to be able to apply mathematical principles and apply them in solving problems in daily life. According to Stepanek (2000) problem-solving is the core of mathematics, and problem-solving is the focus of mathematics learning, as stated by NCTM in (Irwansyah & Retnowati, 2019) Mathematical problem-solving is a process that students go through to solve problems with the following steps: understanding the problem, making a plan or strategy, planning, and revising the answer or solution to the given problem (Asmana et al., 2018). However, in practical learning, many students still experience difficulty solving mathematical problems, particularly complex ones that require the interconnection of multiple concepts. This difficulty is not only caused by a lack of conceptual mastery but also by the high cognitive load experienced by students during the learning process.

According to (Sweller, 1988) cognitive load theory explains that human working memory capacity is limited so that too much or too complex information can hinder the learning process. Cognitive load consists of three components: intrinsic cognitive load, extraneous cognitive load, and germane cognitive load. Intrinsic cognitive load relates to the level of complexity of the material being studied, extraneous cognitive load stems from ineffective learning designs, while germane cognitive load relates to the mental effort students use to construct new knowledge schemas (Santosa et al., 2018) In mathematics learning, these three types of cognitive load significantly influence students' ability to understand concepts and solve problems. Recent research shows that good cognitive load management can help students gain a deeper understanding of mathematics and improve problem-solving skills more effectively (Ngu & Phan, 2024)

Various learning strategies have been developed to help reduce students' cognitive load. One strategy widely recommended in Cognitive Load Theory is the use of worked examples, or fully solved examples of problems. Worked examples help students understand the steps to solving problems through systematic demonstrations, thereby reducing unnecessary cognitive load and increasing learning efficiency. Research shows that worked examples are effective in helping students build conceptual and procedural understanding, particularly in complex mathematics (Hancock-Niemic et al., 2016). Recent studies also indicate that the use of worked examples is one of the most consistent strategies for reducing extraneous cognitive load and increasing the accuracy of mathematical problem-solving.

In addition to worked examples, the Problem-Based Learning (PBL) model is also widely used in mathematics learning because it can improve critical thinking and problem-solving skills. Through PBL, students are encouraged to actively seek solutions to given problems, making the learning process more meaningful. A recent systematic review of 40 PBL studies in mathematics education showed that PBL has a positive impact on problem-solving skills, academic achievement, and various aspects of students' cognitive and metacognitive development (Sari et.al., 2025). However, several studies have shown that problem-based learning can increase students' cognitive load if they lack sufficient prior knowledge to solve the given problem (Jalani & Sern, 2015b). This makes it difficult for students to manage the information they must process simultaneously when solving complex problems.

To address these weaknesses, (Jalani et al., 2014) developed Example Problem-Based Learning (EPBL), a learning model that integrates worked examples and problem solving within a single learning process. The EPBL model consists of three main stages: presentation, consolidation, and reinforcement. In the presentation stage, students are provided with basic knowledge of the concepts being studied. Next, in the consolidation stage, students are provided with worked examples that systematically outline the steps for solving problems. The final stage is reinforcement, which involves providing problem-solving exercises to strengthen students' understanding and skills. According to (Santosa, & Filiz, 2025) gradually presented worked examples can function as cognitive scaffolding, helping students build conceptual understanding before facing more complex problems.

Although extensive research has been conducted on worked examples, Cognitive Load Theory, and Problem-Based Learning, most research focuses on learning outcomes and problem-solving skills. Research specifically examining how the integration of worked examples and problem solving through the EPBL model affects students' cognitive load in solving complex mathematical problems is relatively limited. Furthermore, most previous studies have examined worked examples and PBL separately, leaving little exploration of the effectiveness of their combination in managing cognitive load. This situation indicates a research gap that requires further study.

Based on this description, this study aims to analyze the role of the Example Problem-Based Learning (EPBL) model on students' cognitive load when solving complex mathematical problems. The novelty of this research lies in the integration of worked examples and problem solving within a single learning model to manage students' cognitive load. The results of this study are expected to provide theoretical contributions to the development of Cognitive Load Theory in mathematics learning and provide practical assistance to teachers in designing learning that can reduce students' cognitive load when solving complex mathematical problems.

2. METHOD

2.1 Research Design

This study employed a mixed methods approach with a Concurrent Triangulation design. This design was used to collect quantitative and qualitative data simultaneously, then analyze each data separately and integrate it during the interpretation stage of the research results. This design aimed to gain a more comprehensive understanding of the role of the Example Problem-Based Learning (EPBL) model on students' cognitive load in solving complex mathematical problems (Creswell & Plano Clark, 2018). The independent variable in this study is the Example Problem-Based Learning (EPBL) model, while the dependent variables consist of cognitive load and complex mathematical problem-solving ability. Quantitative data were used to identify changes in students' problem-solving abilities and cognitive load levels after the implementation of EPBL, while qualitative data were used to obtain more in-depth information about students' learning experiences while participating in learning using the EPBL model.

2.2 Participants

The research subjects were eighth-grade students of SMP Negeri 14 Serang City in the 2024-2025 academic year. The research sample consisted of one class with 36 students selected using a purposive sampling technique. Class selection was based on the mathematics teacher's recommendation, taking into account the equivalence of students' academic abilities and the feasibility of implementing the EPBL model during the research. The research was conducted over eight meetings over a period of approximately two months. Prior to the research, the researcher obtained permission from the school and explained the research objectives to students as part of research ethics.

2.3 Instrument

This study used test and non-test instruments. The test instrument was used to measure students' ability to solve complex mathematical problems, while the non-test instrument was used to measure students' cognitive load and obtain information about students' learning experiences during the EPBL model.

Problem-Solving Ability Test

The test instrument consisted of descriptive questions administered during the pretest and posttest. The questions were designed based on indicators of mathematical problem-solving ability, including understanding the problem, planning a solution, implementing a solution strategy, and evaluating the resulting solution (Asmana et al., 2018). Before use, the instrument was validated by three mathematics education experts to ensure the appropriateness of the content, construct, and language used. Instrument reliability was calculated using the Cronbach's Alpha coefficient.

Cognitive Load Questionnaire

Cognitive load was measured using a mental effort rating scale adapted from (Paas & van Merriënboer, 2020) The questionnaire uses a Likert scale in the form of emoticons with nine assessment categories that reflect students' level of mental effort during the learning process. A score of 1 indicates very low mental effort, while a score of 9 indicates very high mental effort. This scale has been widely used in Cognitive Load Theory research to measure students' perceptions of mental load during learning (Santosa et al., 2018)

Figure 1. Cognitive load scale

Interviews

Semi-structured interviews were conducted with students in the research class. The aim was to obtain more in-depth information about students' experiences during learning using the EPBL model, the difficulties they encountered, and the strategies they used to solve complex mathematical problems.

2.4 Research Procedure

The research was conducted in several stages. In the initial stage, students were given a pretest to determine their initial mathematical problem-solving abilities, along with a cognitive questionnaire. Subsequently, learning was carried out using the EPBL model for eight meetings. The first stage in EPBL is Explanation or Presentation, which provides basic material related to the concepts to be learned. The second stage is Understanding, which provides worked examples containing systematic problem-solving steps. At this stage, students are asked to observe, understand, and discuss each solution step given. The third stage is Reinforcement, which provides independent problem-solving exercises to strengthen students' understanding of the concepts learned (Jalani & Sern, 2015b). After the entire learning series was completed, students were given a posttest and a cognitive load questionnaire. Next, students were directed to participate in interviews to strengthen and clarify the results of the quantitative analysis. Data from the interviews and questionnaires were used as a source of triangulation to increase the credibility of the research results.

2.5 Data Analysis

Quantitative data analysis began with a normality test for pretest and posttest scores. If the data were normally distributed, testing continued using a paired sample t-test to determine differences in students' problem-solving abilities before and after implementing the EPBL model. In addition, effect sizes were calculated using Cohen's d to determine the effectiveness of the EPBL model implementation on students' problem-solving abilities and cognitive load.

Cognitive load data were analyzed descriptively using mean scores and categories of students' mental load levels. Next, the relationship between cognitive load and problem-solving abilities was analyzed using Pearson correlation.

Qualitative data obtained from interviews were analyzed using thematic analysis developed by (Braun & Clarke, 2006) The analysis was conducted in six stages: (1) familiarizing the data, (2) conducting initial coding, (3) identifying themes, (4) reviewing the themes, (5) defining and naming the themes, and (6) compiling a report on the analysis results.

3. RESULTS

3.1 Quantitative Data Results

Before implementing the Example Problem-Based Learning (EPBL) model, students were given a pretest to determine their initial ability to solve complex mathematical problems. After completing the entire learning process, students were given a posttest to measure changes in their abilities after receiving the treatment.

3.1.1 Normality Test for Problem-Solving Ability Data

A normality test was conducted on the difference between pretest and posttest scores to determine the type of statistical analysis used. The results of the normality test are presented in table 1.

Based on table 1, a significance value of 0.200 (>0.05) was obtained. These results indicate that the data are normally distributed, allowing for further analysis using a paired sample t-test.

Table 1. Results of normality test on pretest-posttest data

Statistic	Value
N	36
Mean	$2{,}47 \times 10^{-16}$
Std. Deviation	4,93
Sig.	0,200

3.1.2 Paired Sample t-Test Results: Problem-Solving Ability

A paired sample t-test analysis was conducted to determine differences in students' mathematical problem-solving abilities before and after implementing the EPBL model. The test results are presented in table 2.

Table 2. The results of the paired t-test statistical test on the pretest-posttest

Statistic	Value
Pretest Average	47.50
Posttest average	76.39
Mean	-28.88
Std. Deviation	28.57
T	-6.066
Df	36
Effect Size (d)	1,011
Sig. (2 tailed)	< 0,001

The test results showed a significant difference between the pretest and posttest scores, with a t-value of -6.066 and $p < 0.001$. The effect size of 1.011 indicates that the implementation of the EPBL model had a significant impact on improving students' mathematical problem-solving abilities.

3.1.3 Cognitive Load Data Normality Test

In addition to problem-solving abilities, this study also measured students' cognitive load through a questionnaire administered before and after the implementation of the EPBL model. The results of the questionnaire data normality test are presented in table 3.

Table 3. Normality test results for cognitive load

Statistic	Value
N	36
Mean	3.2×10^{-15}
Std. Deviation	16,05
Sig.	0,200

A significance value of 0.200 (>0.05) indicates that the cognitive load data is normally distributed, allowing for further analysis using a paired sample t-test.

3.1.4 Results of the Paired Sample t-Test for Cognitive Load

The results of the paired sample t-test analysis of cognitive load scores are presented in table 4.

Table 4. The Results Of The Paired T-Test Cognitive Load

Statistic	Value
Pretest Average	50,25
Posttest average	17,00
Mean	33,25
Std. Deviation	14,65
T	13,617
Df	36
Effect Size (d)	2,269
Sig. (2 tailed)	< 0,001

Based on table 4, the t-value was 13.617 with a significance value of $p < 0.001$. These results indicate a significant difference between cognitive load scores before and after the implementation of the EPBL model. The effect size value of 2.269 indicates that the implementation of the EPBL model had a significant impact on reducing students' cognitive load.

3.2 Qualitative Data Results

Qualitative data was obtained through semi-structured interviews with several students following the learning process using the EPBL model. The data were analyzed using thematic analysis to identify codes, categories, and themes that describe the students' experiences during the learning process. The analysis revealed two main themes explaining the role of EPBL in mathematics learning: (1) ease of understanding the material and (2) learning comfort.

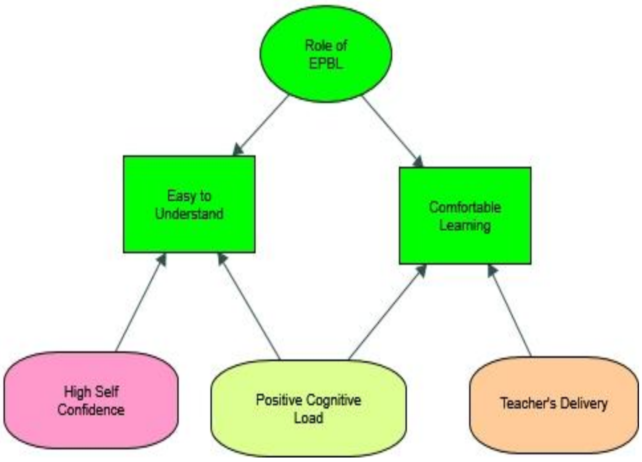

Figure 2. The results of coding in the thematic analysis

3.2.1 Ease of Understanding the Material

The first theme indicates that EPBL helps students understand mathematics more easily by presenting example problems that are solved step by step. Most students stated that the systematic steps made it easier for them to follow the problem-solving process.

Some student statements that represent this theme include:

"Easy to understand, so it's easy to digest too, so you can do your assignments much easier."
"You can focus more on learning and it's easier to understand."

These statements indicate that the use of worked examples in EPBL helps students understand concepts and problem-solving procedures more clearly.

3.2.2 Learning Comfort

The second theme indicates that EPBL creates a comfortable learning environment and does not cause excessive pressure during the learning process. Students feel more relaxed and focused when participating in lessons using the EPBL model.

One student statement that illustrates this theme is as follows:
"I didn't feel burdened at all, because the way she explained the material was so engaging, it wasn't boring."

Furthermore, several students stated that the teacher's systematic delivery method and use of clear examples made the learning process more enjoyable.
Based on the results of the thematic analysis, these two themes indicate that EPBL plays a role in helping students understand mathematics material while creating a more comfortable learning experience during the process of solving complex mathematical problems.

4. Discussion

4.1 The Role of EPBL in Complex Mathematical Problem-Solving Skills

The results of this study indicate that students' mathematical problem-solving skills improved after participating in learning using the Example Problem-Based Learning (EPBL) model. This improvement was demonstrated by a significant difference between pretest and posttest scores, with a t-value of -6.066 ($p < 0.001$) and an effect size of 1.011, which is considered large. This finding indicates that the implementation of EPBL positively contributed to students' ability to solve complex mathematical problems. This improvement in problem-solving skills can be explained by the main characteristic of EPBL, which integrates worked examples and problem-solving activities within a single learning sequence. In the presentation phase, students gain basic knowledge of the concepts to be learned. The consolidation phase provides students with the opportunity to learn problem-solving steps through worked examples, while the reinforcement phase provides students with the opportunity to apply the acquired knowledge to more independent problem-solving situations (Jalani et al., 2014)

The presence of worked examples in learning helps students systematically understand problem-solving procedures before they are asked to solve problems independently. This allows students to build a better knowledge framework, enabling them to identify relevant information, select appropriate problem-solving strategies, and evaluate their solutions. According to Hancock-Niemic et al., (2016), the use of worked examples can improve learning efficiency because students receive clear and structured examples of solutions before facing more complex tasks.

The findings of this study align with those of Jalani & Sern, (2015a), who found that integrating worked examples and problem-solving through EPBL significantly improved students' mathematical problem-solving abilities. These results also support a systematic review conducted by (Ayari , et al., 2025), which showed that problem-based learning positively impacts students' problem-solving and mathematical reasoning abilities. Therefore, the improvement in problem-solving abilities achieved in this study indicates that EPBL can be an effective learning alternative to help students solve complex mathematical problems.

4.2 The Role of EPBL on Students' Cognitive Load

In addition to improving problem-solving abilities, the results of this study indicate that the implementation of EPBL significantly reduced students' cognitive load. This is demonstrated by the difference in cognitive load scores before and after learning, with a t-value of 13.617 ($p < 0.001$) and an effect size of 2.269, which is considered very large. These findings indicate that students experienced lower mental load after participating in learning using the EPBL model. The decrease in cognitive load found in this study can be explained through the perspective of Cognitive Load Theory proposed by Sweller, (1988) This theory explains that human working memory capacity is limited, so inappropriate learning designs can increase students' cognitive load. In EPBL, the use of worked examples during the consolidation stage helps students understand the steps to solving problems without having to independently search for strategies from the start. This reduces extraneous cognitive load, allowing students' cognitive resources to be more focused on understanding concepts and building knowledge schemas.

These findings also support research by Santosa, (2018) which showed that the use of worked examples can help reduce students' mental load during the mathematics learning process. Furthermore, (Ngu & Phan, 2024)explained that learning strategies that provide structured comparisons of examples and solutions can increase the efficiency of working memory use and accelerate the formation of conceptual schemas. Thus, the reduction in cognitive load found in this study indicates that EPBL is able to create a learning environment more suited to students' cognitive capacities. The results of this study also indicate that reduced cognitive load contributes to improved problem-solving abilities. When students are no longer burdened by the complex process of finding strategies, they can focus on understanding concepts and applying problem-solving procedures more effectively. This condition indicates that cognitive load management is a critical factor in successful mathematics learning.

4.3 Qualitative Findings on the Role of EPBL

The results of the thematic analysis indicate that there are two main themes explaining the role of EPBL in mathematics learning: ease of understanding the material and learning comfort. These two themes emerged consistently among the majority of respondents interviewed after participating in learning using the EPBL model.

The first theme is ease of understanding the material. Students stated that the solution steps provided through worked examples helped them understand the concepts and problem-solving procedures more clearly. The systematic nature of the examples makes it easier for students to follow the thought processes required to solve math problems. This finding indicates that EPBL not only helps students obtain answers but also helps them understand the solution process used. The second theme is learning comfort. Most students stated that learning using EPBL provides a more relaxed learning atmosphere, is less stressful, and does not overburden them. The gradual presentation of the material and teacher support throughout the learning process make students feel more confident in participating in learning activities. This finding indicates that EPBL is able to create a learning environment that supports active student engagement without causing excessive cognitive pressure.

4.4 Integration of Quantitative and Qualitative Findings

The results of the quantitative and qualitative research show mutually supportive findings. Quantitatively, the implementation of EPBL has been shown to improve mathematical problem-solving skills while reducing students' cognitive load. These findings are supported by interview results, which indicate that students found the material easier to understand and more comfortable during the learning process. The ease of understanding experienced by students indicates that the use of worked examples in EPBL facilitates the formation of knowledge schemas necessary for problem-solving. Meanwhile, the students' perceived learning comfort indicates that learning proceeds without excessive mental load. Thus, the results of this study provide evidence that EPBL not only plays a role in improving learning outcomes but also helps students manage their cognitive resources during the process of solving complex mathematical problems.

Overall, the findings of this study reinforce the assumption that the integration of worked examples and problem-solving in the EPBL model is an effective learning strategy for improving problem-solving skills while reducing students' cognitive load. These findings contribute to the development of Cognitive Load Theory in mathematics learning and can provide an alternative for teachers in designing more effective learning strategies for dealing with complex mathematical problems.

5. CONCLUSION

This study shows that the implementation of the Example Problem-Based Learning (EPBL) model contributes to improving students' ability to solve complex mathematical problems while helping reduce cognitive load during the learning process. These quantitative findings are supported by the results of qualitative analysis which show that the use of worked examples in EPBL helps students understand concepts and problem-solving procedures more easily and creates a more comfortable learning atmosphere. The results of this study provide empirical evidence that the integration of worked examples and problem-solving activities in the EPBL model can be an effective learning strategy to support cognitive load management while improving mathematical problem-solving abilities. Therefore, the EPBL model has the potential to be an alternative learning model that can be implemented by mathematics teachers to help students face complex mathematical problems more effectively.

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