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GOAL-FREE PROBLEMS IN MATHEMATICS EDUCATION: A SYSTEMATIC REVIEW OF COGNITIVE LOAD AND PROBLEM-SOLVING RESEARCH

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ABSTRACT

Goal-Free Problems (GFP), based on Cognitive Load Theory (CLT), is an instructional strategy that reduces extraneous cognitive load by eliminating specific end goals from mathematical tasks. Although widely implemented in mathematics education, empirical findings remain fragmented and lack systematic synthesis. This study systematically reviews research on Goal-Free Problems with a focus on cognitive load and mathematical problem-solving. Literature was identified through Scopus, ERIC, and Google Scholar using Publish or Perish, covering publications from 2016–2026. Following the PRISMA 2020 guidelines, ten eligible studies were analyzed using narrative synthesis. The results indicate that Goal-Free Problems consistently reduce cognitive load and support learning outcomes such as transfer, retention, reasoning, flexible thinking, and higher-order thinking skills. However, their effectiveness is influenced by task complexity, prior knowledge, and instructional design. The review also reveals that direct evidence regarding mathematical problem-solving ability remains limited, as most studies emphasize cognitive load and related cognitive variables. These findings highlight the need for further experimental research examining mathematical problem-solving as the primary outcome.

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1. INTRODUCTION

Mathematics education aims not only to develop conceptual understanding but also to foster a range of higher-order cognitive abilities, including transfer learning, mathematical reasoning, creative thinking, flexible thinking, higher-order thinking skills (HOTS), learning retention, and mathematical problem-solving ability. However, the development of these competencies is often constrained by the limited capacity of students' working memory to process complex information simultaneously. Cognitive Load Theory (CLT), proposed by Sweller (1994), explains that learning is determined by the interaction between the limited capacity of working memory and the unlimited storage capacity of long-term memory, where knowledge is organized into cognitive schemas. Since new information must be processed through working memory before being integrated into long-term memory, excessive cognitive demands may hinder meaningful learning (Sweller et al., 2019). Accordingly, Kirschner et al. (2018) argued that effective instructional design should align with the characteristics of human cognitive architecture.

Within the Cognitive Load Theory framework, cognitive load consists of *intrinsic cognitive load*, *extraneous cognitive load*, and *germane cognitive load*. *Intrinsic cognitive load* is associated with the inherent complexity of learning materials, *extraneous cognitive load* arises from ineffective instructional presentation, whereas *germane cognitive load* reflects the cognitive resources devoted to schema construction. Consequently, instructional strategies that minimize *extraneous cognitive load* are expected to facilitate schema acquisition and improve students' learning outcomes in mathematics (Purnama & Retnowati, 2021).

One instructional strategy developed based on Cognitive Load Theory principles is Goal-Free Problems. Unlike conventional goal-given problems that require learners to reach a specific end goal, Goal-Free Problems presents tasks without predetermined objectives, encouraging students to explore multiple solution pathways using the available information. By reducing reliance on means-end analysis, Goal-Free Problems allows students to focus on conceptual relationships rather than merely searching for a correct answer, thereby reducing unnecessary cognitive load (Retnowati & Maulidya, 2018). Moreover, this strategy has been reported to promote flexible thinking in mathematical problem solving (Maulidya et al., 2017). These characteristics suggest that Goal-Free Problems has the potential not only to optimize cognitive load management but also to enhance students' mathematical problem-solving ability.

Previous studies have demonstrated the potential of Goal-Free Problems to improve mathematics learning through more effective cognitive load management. Purnama and Retnowati (2021) reported that Goal-Free Problems reduced cognitive load while improving transfer learning in triangle similarity topics. Similar findings were reported by Octaviola and Retnowati (2023) in collaborative geometry learning. Furthermore, Aprillia and Retnowati (2025) found that although Goal-Free Problems did not significantly improve retention and transfer directly, it significantly reduced students' cognitive load and became more effective when combined with guided questions. In addition to cognitive load management, several studies have suggested that Goal-Free Problems may contribute to mathematical problem-solving ability. Setiawan and Susanah (2023) reported a classical mastery level of 79.31% following collaborative Goal-Free Problems implementation, while Barnett (2025) highlighted its potential to improve problem-solving performance, self-confidence, and reduce mathematics anxiety.

Despite these promising findings, empirical evidence regarding the effectiveness of Goal-Free Problems remains fragmented. Existing studies differ considerably in research characteristics, instructional contexts, and implementation designs, making comprehensive conclusions difficult to establish. Existing studies differ considerably in research characteristics, instructional contexts, and implementation designs, making comprehensive conclusions difficult to establish. Additionally, the trajectory of Goal-Free Problems research including its growth, publication patterns, and contextual variations has not been systematically mapped, limiting a full understanding of how this field has developed. Moreover, most studies focus on cognitive load and related cognitive variables rather than directly examining mathematical problem-solving ability. Consequently, a systematic synthesis is required to identify research trends, summarize empirical findings, and evaluate the effectiveness of Goal-Free Problems in mathematics education more comprehensively.

To address this gap, the present study employs a Systematic Literature Review (SLR) following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines to identify, evaluate, and synthesize empirical evidence concerning the implementation of Goal-Free Problems in mathematics education. The findings are expected to provide a comprehensive understanding of current research trends, highlight existing research gaps, and offer theoretical and practical implications for the development of mathematics instruction. To achieve these aims, the present study addresses the following research questions:

RQ1: How has Goal-Free Problems research in mathematics education developed in terms of publication output over time?

RQ2: How have Goal-Free Problems been implemented across different educational contexts?

RQ3: What effects do Goal-Free Problems have on cognitive load and mathematical problem-solving ability?

RQ4: What research gaps remain for future investigation?

2. METHOD

This study employed a Systematic Literature Review (SLR) approach to identify, evaluate, and synthesize empirical studies on the implementation of Goal-Free Problems in mathematics education. The review process followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines (Page et al., 2021), which consist of four stages: identification, screening, eligibility, and inclusion.

2.1 Literature Search Strategy

The literature search was conducted using the Scopus, ERIC, and Google Scholar databases, with Publish or Perish (PoP) employed as a search tool, covering publications from 2016 to 2026. The search strategy was developed based on three main concepts: instructional strategy, underlying theory, and mathematics education context. The following search string was applied:

("Goal-Free Problems" OR "Goal Free Problem") AND ("Cognitive Load" OR "Cognitive Load Theory") AND ("Mathematics" OR "Mathematics Education" OR "Mathematics Learning")

The search was performed in both Indonesian and English. The retrieved studies were subsequently screened according to predetermined inclusion and exclusion criteria, including verification of publication quality through Scopus or SINTA indexing.

2.2 Article Selection Criteria

The identified studies were screened to ensure their relevance to the research objectives and the quality of the evidence included in the review. The selection process was based on predetermined inclusion and exclusion criteria, covering publication year, publication type, research topic, research method, variables investigated, research participants, full-text availability, and publication language. The inclusion and exclusion criteria applied in this study are presented in table 1.

Table 1. Article Selection Criteria

Aspect	Inclusion Criteria	Exclusion Criteria
Publication Year	Articles published between 2016 and 2026	Articles published before 2016 or after 2026
Publication Type	Peer-reviewed journal articles or conference proceedings indexed in Scopus or SINTA	Books, theses, dissertations, review articles, editorials, non-peer-reviewed proceedings, or non-indexed publications
Research Topic	Goal-Free Problems in mathematics education	Studies unrelated to Goal-Free Problems or mathematics education
Research Variables	Mathematical problem-solving, cognitive load, transfer, reasoning, flexible thinking, creative thinking, HOTS, or learning retention	Studies unrelated to these variables or Goal-Free Problems learning outcomes
Research Participants	Junior high school, senior high school, or university students	Teachers, lecturers, elementary students, early childhood learners, or non-educational populations
Availability	Full-text articles accessible for review	Articles available only as abstracts, inaccessible full texts, or incomplete documents

2.3 Article Selection Process

The article selection process followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines (Page et al., 2021). The initial literature search identified 1281 records from the selected databases. After preliminary screening based on topic relevance, full-text availability, and publication indexing criteria, 68 articles were retained for the screening stage. Subsequently, title and abstract screening resulted in 28 articles being subjected to full-text assessment. Following the eligibility evaluation, 18 articles were excluded because they did not meet the predefined inclusion criteria. Consequently, 10 articles were included in the final qualitative synthesis. The article selection process is illustrated in Figure 1.

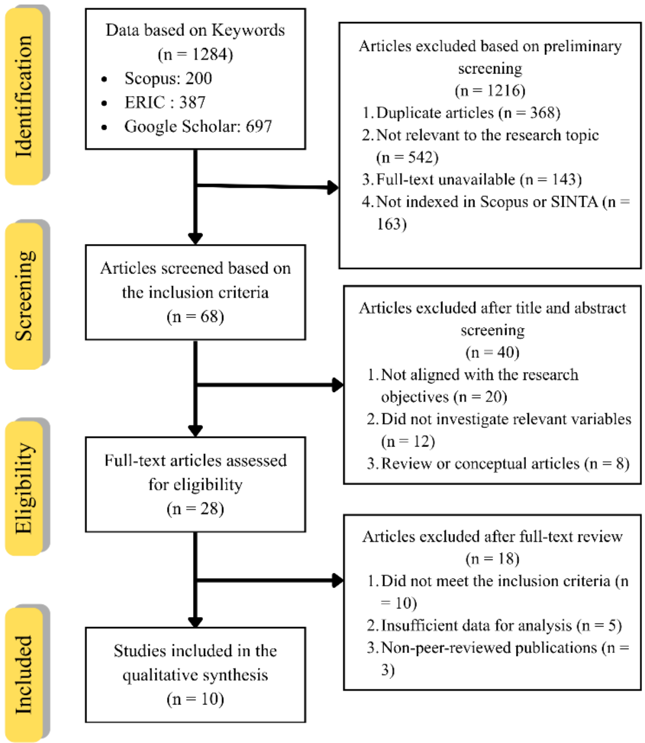


Figure 1. PRISMA Flow Diagram for Literature Selection

2.4 Data Extraction

Data extraction was conducted using a structured extraction form developed in accordance with the objectives of the study. The extracted information included the authors, publication year, journal indexing status, research objectives, research methods, learning topics, research participants, principal findings, study limitations, and identified research gaps. The extracted data were subsequently organized into a review matrix to facilitate the synthesis and comparative analysis of the included studies.

2.5 Data Synthesis and Analysis

The extracted data were analyzed using a narrative synthesis approach following the framework proposed by Popay et al. (2006). The synthesis process consisted of four stages: (1) developing a preliminary theoretical framework based on Cognitive Load Theory (CLT) to guide the interpretation of findings; (2) constructing an initial description of each study through thematic coding based on research variables, methodology, participants, and key findings; (3) synthesizing the evidence by grouping and comparing the studies using a review matrix; and (4) assessing the strength of the evidence by considering the consistency of findings, methodological quality, and sample size. Contradictory findings were interpreted by identifying contextual factors that could explain such differences, including task complexity, learners' prior expertise, and variations in instructional design.

3. RESULTS AND DISCUSSION

3.1. Results

Based on the article selection process following the PRISMA 2020 guidelines, 10 studies met the predefined inclusion criteria and were included in the qualitative synthesis. The characteristics of the selected studies include the authors, publication year, journal indexing status, research methods, research focus, research participants, main findings, study limitations, and identified research gaps. A summary of the characteristics of the included studies is presented in Table 2.

Table 2. Characteristics of the Reviewed Goal-Free Problems Studies

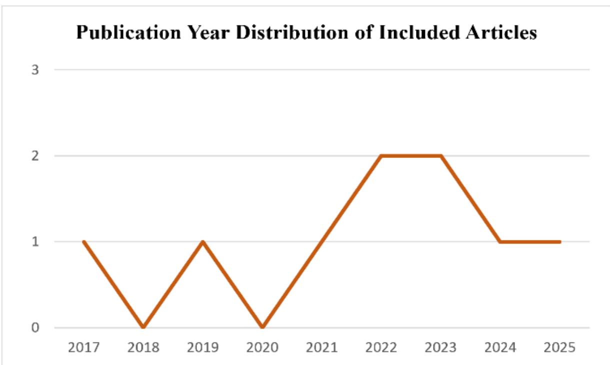
No	Author(s) & Year	Research Method	Participants	Research Focus	Main Findings
1	Maulidya et al. (2017)	Experimental	Junior High School Students	Flexible Thinking	Goal-Free Problems improved students' flexible thinking skills.
2	Sugiman et al. (2019)	Experimental	Junior High School Students	Transfer Learning	Collaborative Goal-Free Problems instruction was more effective than individual learning in improving transfer learning.
3	Purnama & Retnowati (2021)	Factorial Experimental	Junior High School Students	Transfer, Retention, Cognitive Load	Goal-Free Problems enhanced learning retention and transfer while reducing cognitive load.
4	Maulida et al.. (2022)	Factorial Experimental	Junior High School Students	Transfer, Reasoning, Cognitive Load	Goal-Free Problems improved transfer learning and mathematical reasoning while reducing cognitive load.
5	Pradinar & Pujiastuti (2022)	Mixed Methods	Senior High School Students	Creative Thinking	Goal-Free Problems enhanced students' mathematical creative thinking skills.
6	Setiawan & Susanah (2023)	Quantitative Descriptive	Junior High School Students	Mathematical Problem Solving	Students achieved a classical mastery level of 79.31% in mathematical problem-solving ability.
7	Octaviola & Retnowati (2023)	True Experimental	Junior High School Students	Transfer Learning and Cognitive Load	Goal-Free Problems improved learning retention and transfer, but showed no significant effect on cognitive load.

8	Samo et al. (2024)	Quasi-Experimental	University Students	HOTS and Cognitive Load	HOTS improved, while students experienced lower cognitive load.
9	Aprillia & Retnowati (2025)	Factorial Experimental	Junior High School Students	Retention, Transfer Learning, Cognitive Load	Goal-Free Problems significantly affected cognitive load and interacted positively with guided questions.
10	Samo et al. (2025)	Quasi-Experimental	University Students	HOTS and Cognitive Load	HOTS improved significantly, accompanied by a significant reduction in cognitive load.

Based on table 2, research on Goal-Free Problems in mathematics education has shown a relatively consistent development from 2017 to 2025. Most studies employed experimental or quasi-experimental designs, with junior high school students serving as the predominant research participants. The research has focused not only on learning outcomes but also on cognitive aspects, including cognitive load, transfer learning, mathematical reasoning, higher-order thinking skills (HOTS), and creative thinking. These findings indicate that Goal-Free Problems have increasingly been adopted as an instructional strategy grounded in Cognitive Load Theory (CLT).

3.2. Discussion

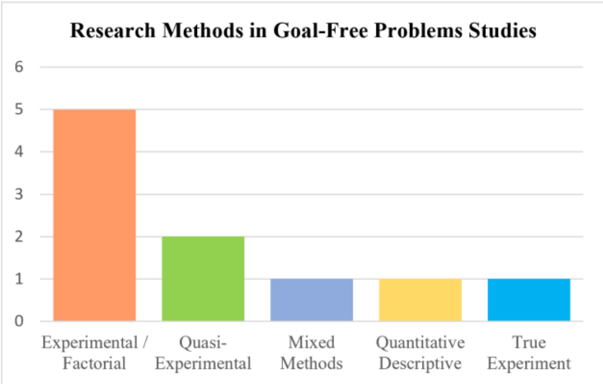
The synthesis of the ten included studies indicates that Goal-Free Problems have been consistently developed as an instructional strategy grounded in Cognitive Load Theory to optimize students' cognitive processing during mathematics learning. The predominance of studies focusing on cognitive load, transfer learning, and other higher-order cognitive abilities suggests that current research has primarily emphasized the cognitive mechanisms underlying learning rather than directly examining mathematical problem-solving ability. This pattern highlights the theoretical importance of Goal-Free Problems in reducing unnecessary cognitive demands while simultaneously revealing a significant gap in empirical evidence regarding their direct impact on mathematical problem-solving performance.



Graph 1. Number of Articles Meeting the Inclusion Criteria by Publication Year

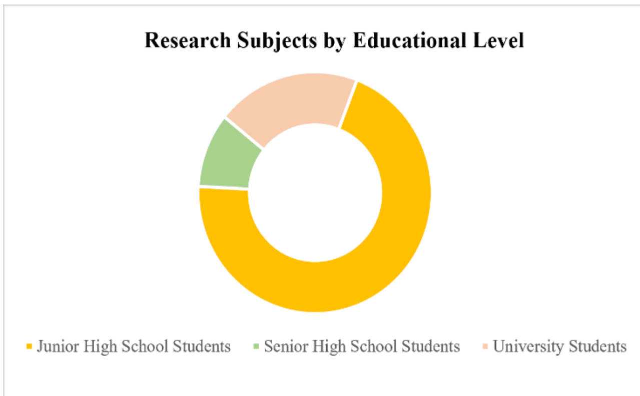
Based on figure 1, research on Goal-Free Problems has shown continuous development since 2017, with a notable increase in publications during 2022–2023, indicating growing scholarly interest in this instructional strategy. The synthesized findings can be interpreted from two main perspectives: the effectiveness of Goal-Free Problems in managing cognitive load and its potential contribution to students' mathematical problem-solving ability.

3.2.1. Characteristics of Goal-Free Problems Research



Graph 2. Distribution of Research Methods in Goal-Free Problems Studies

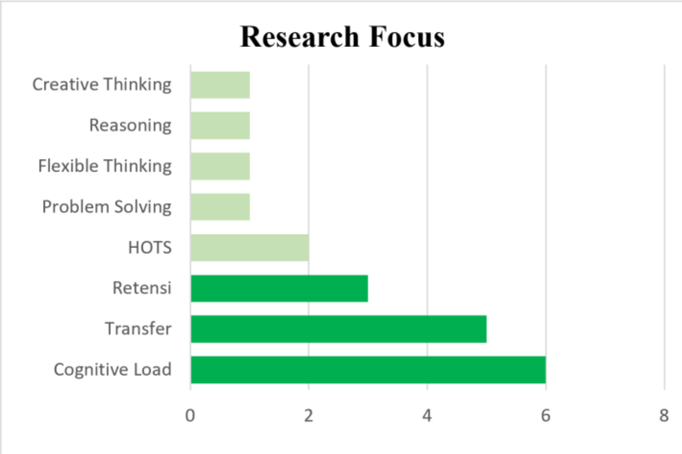
Based on Figure 2, most studies on Goal-Free Problems employed experimental or factorial experimental designs ($n = 5$), followed by quasi-experimental ($n = 2$), mixed methods ($n = 1$), quantitative descriptive ($n = 1$), and true experimental ($n = 1$), approaches. The predominance of experimental designs suggests that researchers have primarily sought to establish causal evidence regarding the effectiveness of Goal-Free Problems. Nevertheless, the diversity of research designs contributes to variations in reported findings, indicating that comparisons across studies should be interpreted with consideration of methodological differences.



Graph 3. Distribution of Research Subjects by Educational Level

Based on Figure 3, the reviewed studies predominantly involved junior high school students ($n = 7$), followed by university students ($n = 2$) and senior high school students ($n = 1$). The predominance of junior high school participants may be attributed to the complexity of geometry and algebra topics commonly taught at this level, making them appropriate contexts for evaluating instructional strategies derived from Cognitive Load Theory. The limited evidence from senior high school and university settings suggests the need for broader investigations across different educational levels.

3.2.2. The Effectiveness of Goal-Free Problems on Cognitive Load



Graph 4. Distribution of Research Variables Investigated in Goal-Free Problems Studies

As shown in Figure 4, cognitive load is the most frequently investigated variable ($n = 6$), followed by transfer learning ($n = 5$) and learning retention ($n = 3$). This finding is consistent with the theoretical foundation of Goal-Free Problems, which is rooted in Cognitive Load Theory. Eliminating specific end goals is assumed to reduce students' reliance on means-end analysis, thereby allowing working memory resources to be allocated more efficiently for schema construction (Sweller, 1994).

Overall, the synthesized evidence suggests that Goal-Free Problems tend to produce lower cognitive load than conventional goal-given problems by reducing unnecessary cognitive processing. Purnama and Retnowati (2021) and Aprillia and Retnowati (2025) empirically demonstrated significant reductions in students' cognitive load in geometry learning. Similar findings were reported by Sugiman et al. (2019) and Maulida et al. (2022), who found that collaborative *Goal-Free Problems* were more effective than conventional approaches in managing cognitive load..

However, several inconsistent findings warrant further interpretation. Octaviola and Retnowati (2023) reported that although Goal-Free Problems improved retention and transfer, their effect on cognitive load was not statistically significant. This finding may be explained by the high element interactivity of three-dimensional geometry tasks, where high intrinsic cognitive load remains despite reductions in extraneous cognitive load (Sweller, 1994). Similarly, Samo et al. (2024) reported non-significant reductions in cognitive load among university students, which may reflect the expertise reversal effect, whereby instructional strategies effective for novice learners become less beneficial for learners with greater prior knowledge (Kirschner et al., 2018).

3.2.3. The Effectiveness of Goal-Free Problems on Mathematical Problem-Solving Ability

Based on Figure 4, mathematical problem-solving ability is the least frequently investigated variable ($n = 1$), despite its close conceptual relationship with transfer learning, flexible thinking, reasoning, and higher-order thinking skills. This imbalance represents an important research gap. Among the ten reviewed studies, only Setiawan and Susanah (2023) explicitly investigated mathematical problem-solving ability as the primary outcome, reporting a classical mastery level of 79.31%. In contrast, most studies focused on related cognitive variables, including transfer learning, flexible thinking, reasoning, and higher-order thinking skills (HOTS), rather than directly measuring mathematical problem-solving ability. Although these variables are conceptually linked to problem-solving performance, they cannot be regarded as direct evidence of improved mathematical problem-solving ability. This finding highlights an important research gap and underscores the need for further empirical studies that explicitly examine mathematical problem-solving as the primary outcome variable (Retnowati & Maulidya, 2018).

The primary limitation identified in this synthesis is that most studies employed transfer learning, learning retention, mathematical reasoning, and flexible thinking as proxy variables for mathematical problem-solving ability, rather than measuring it directly. Although these variables are conceptually related to mathematical problem-solving, improvements in these constructs cannot be interpreted as direct evidence of comprehensive improvements in students' mathematical problem-solving ability. This finding highlights an important research gap and underscores the need for future empirical studies employing more rigorous methodological designs that explicitly examine mathematical problem-solving ability as the primary outcome variable.

3.2.4. Factors Moderating the Effectiveness of Goal-Free Problems

The inconsistencies identified in this review do not necessarily weaken the position of *Goal-Free Problems* as an effective instructional strategy. Instead, they indicate that its effectiveness is conditional upon several moderating factors. First, task complexity influences the extent to which *Goal-Free Problems* reduce cognitive load, as reflected by the different findings reported by Purnama and Retnowati (2021) and Octaviola and Retnowati (2023). Second, learners' prior knowledge or expertise plays an important role, with novice learners generally benefiting more than experienced learners, consistent with the expertise reversal effect (Kirschner et al., 2018). Third, the integration of Goal-Free Problems with complementary instructional strategies, such as guided questions (Aprillia & Retnowati, 2025) and collaborative learning approaches (Purnama & Retnowati, 2021; Sugiman et al., 2019) suggests that the effectiveness of Goal-Free Problems can be enhanced through appropriate instructional design. Fourth, methodological variations across the reviewed studies, as illustrated in Figure 2, also contributed to differences in the reported findings, highlighting the need for greater methodological standardization in future Goal-Free Problems research.

Overall, the synthesized evidence suggests that Goal-Free Problems represent a promising instructional strategy in mathematics education by facilitating more effective cognitive load management and supporting higher-order cognitive processes, including transfer learning, retention, reasoning, and flexible thinking. However, as illustrated in Figure 4, existing research has predominantly focused on cognitive load and related cognitive variables, whereas direct investigations of mathematical problem-solving ability remain scarce. This finding highlights an important research gap and underscores the need for future experimental studies that explicitly examine mathematical problem-solving ability as the primary outcome variable across diverse mathematical topics and educational levels.

4. CONCLUSION

This systematic review synthesized ten empirical studies on the implementation of Goal-Free Problems in mathematics education. The findings indicate that Goal-Free Problems, as an instructional strategy grounded in Cognitive Load Theory, consistently demonstrate potential for reducing unnecessary cognitive load while supporting various cognitive outcomes, including transfer learning, retention, reasoning, flexible thinking, and higher-order thinking skills.

Nevertheless, empirical evidence regarding their direct impact on mathematical problem-solving ability remains limited, as most existing studies employ related cognitive constructs rather than measuring problem-solving performance explicitly. Consequently, the effectiveness of Goal-Free Problems for improving mathematical problem-solving ability cannot yet be generalized.

The findings of this review suggest that Goal-Free Problems may serve as an alternative instructional strategy for mathematics learning, particularly in cognitively demanding topics and for learners with limited prior knowledge. Future research should prioritize mathematical problem-solving ability as the primary outcome variable while employing more rigorous experimental designs across broader mathematical topics and educational levels to strengthen the empirical evidence in this field.

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