What Does Defragmenting Research Reveal about Solving Mathematical Problems? A Systematic Literature Review

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***Abstract*—Research on defragmentation in mathematics education has developed in response to the issue of fragmented thinking structures that often hinder students' success in solving mathematical problems. This Systematic Literature Review (SLR) aims to analyze findings from studies on defragmentation in addressing these challenges. A total of 17 peer-reviewed articles published between 2019 and 2024 in Scopus or SINTA-indexed journals were systematically and thematically analyzed. The results show that defragmentation strategies help students overcome various errors in mathematical problem-solving by enabling the diagnosis of thinking errors and supporting the design of more guided and coherent intervention strategies. The findings imply that defragmentation can serve as an alternative instructional strategy to strengthen students' conceptual understanding in mathematics learning.**

***Keywords*—defragmentation intervention, problem solving, mathematics learning**

I. Introduction

Mathematical problem-solving requires the integration of various cognitive skills, including conceptual understanding, procedural knowledge, and logical reasoning [1, 2]. However, many students encounter difficulties or even fail due to fragmented cognitive structures, which are disconnected pieces of knowledge that hinder their ability to transfer and apply concepts effectively [3, 4].

To address this issue, teachers are expected to provide meaningful support rather than remain passive or judgmental. Common interventions include remedial instruction, one-on-one tutoring, extended learning time, and strategies to increase student engagement [5]. Although often limited in scope, these interventions aim to activate, restructure, or build new cognitive schemas that foster deeper understanding. This process is referred to in this study as the defragmentation of thinking structures a systematic effort to reorganize fragmented knowledge into a more coherent and integrated form to enhance mathematical problem-solving [6].

Defragmentation, originally derived from computer science, has been conceptually adapted in education to describe the process of reorganizing disconnected or disjointed knowledge structures for better learning integration [7]. In mathematics education, this is commonly facilitated through scaffolding techniques such as reviewing, restructuring, and conceptual development that help students bridge gaps in their understanding and improve cognitive coherence [8, 9].

The theoretical foundations of defragmentation align closely with Vygotsky's Zone of Proximal Development (ZPD) [10], where learners benefit from targeted guidance to achieve higher levels of understanding beyond their current capabilities. Scaffolding within this zone supports the internalization of new knowledge by gradually transferring cognitive responsibility to the student. Additionally, Cognitive Load Theory [11] explains how structured interventions can reduce extraneous cognitive load, enabling students to process complex mathematical ideas more effectively and enhance their problem-solving performance.

This study presents a Systematic Literature Review (SLR) to map the current landscape of defragmentation research in mathematics education. It aims to synthesize findings on cognitive errors, classify defragmentation strategies, and assess their effectiveness in improving mathematical problem-solving. Specifically, the study addresses the following research questions:

(1) How are the trends in defragmentation research on mathematical problems?
(2) What types of errors are addressed in defragmenting research?
(3) How are the causes of student errors diagnosed and addressed through defragmenting interventions?
(4) What types of defragmentation are used in mathematical problem-solving?

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II. METHODS

This study uses a Systematic Literature Review (SLR) to examine the role of defragmentation in mathematical problem-solving, adhering to the PRISMA guidelines for quality and transparency. The review includes empirical, peer-reviewed studies published between 2019 and 2024, conducted in schools (junior high, senior high, or universities), and indexed in SINTA or Scopus, to ensure the quality of the findings. Studies not focusing on defragmentation, published before 2019, or lacking peer review were excluded. The literature search was conducted using Publish or Perish 8 with relevant keywords in both Indonesian and English, with additional studies identified through snowball sampling. Out of 281 references, 17 articles met the inclusion criteria and were analyzed, as shown in Fig. 1, which presents the PRISMA flow diagram generated using Covidence. The quality of studies was assessed using the JBI Critical Appraisal Checklist, evaluating clarity, validity, and methodological rigor, with the review process carried out by one primary researcher and two independent reviewers. Data management was facilitated using Covidence, and a thematic analysis was conducted to categorize the findings into cognitive errors, defragmentation strategies, and scaffolding interventions. The results of this categorization are presented in Fig. 2.

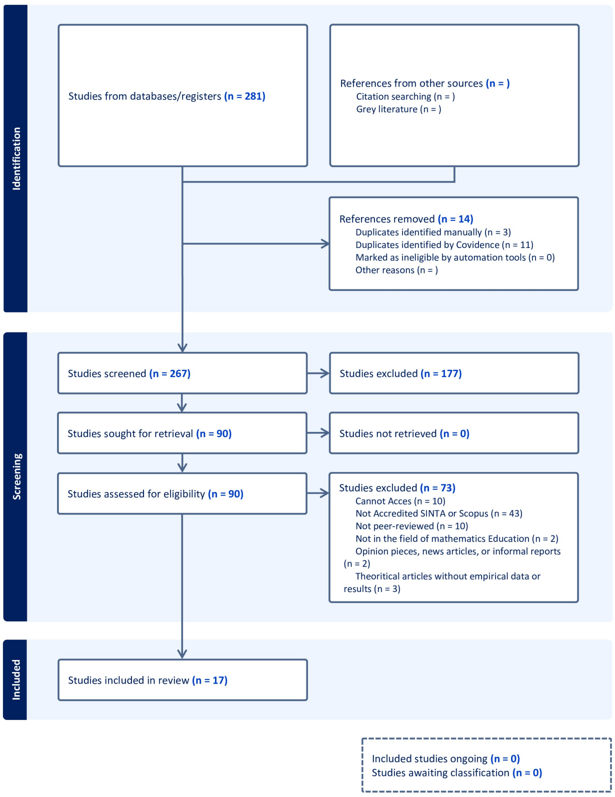

Fig. 1. PRISMA flow diagram from covidence.

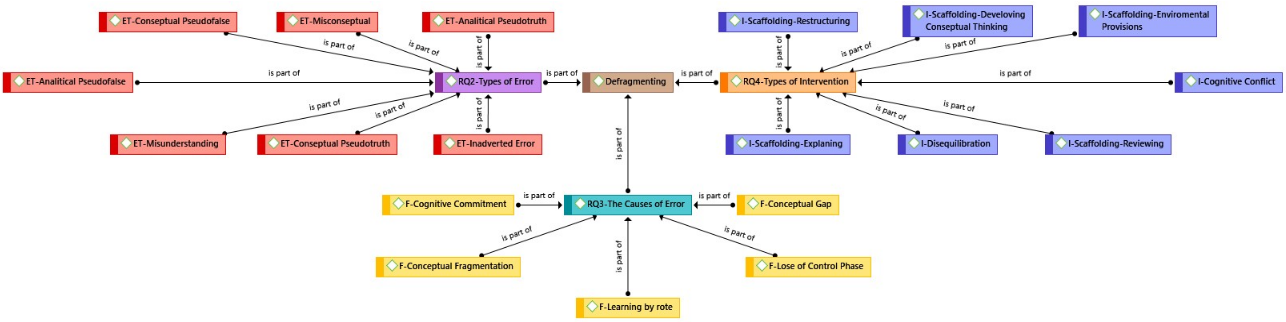

Fig. 2. Results of selective coding of error types, causes, and interventions in defragmentation research in solving mathematics problems.

III. RESULT AND DISCUSSION

In this section, we present the key findings of the study and discuss them in relation to existing literature. The classification of error types, causes, and interventions is summarized in Fig. 2. We focus on emerging patterns and the implications of these results for practice and future research. Additionally, we address the limitations of the studies analyzed and offer suggestions for further research in this field.

A. How are the Trends in Defragmentation Research on Mathematical Problems?

This section discusses the emerging patterns and trends in the field by examining the areas of focus and educational levels of the existing research. From the 17 articles that met the criteria, a trend was extracted and visualized in a Sankey diagram (Fig. 3). The data reveals that the defragmentation research trend has shown a significant increase in publications since 2022 (23%), reaching its peak in 2023 (27%). The majority of these studies focus on secondary education, specifically Junior High School (45%) and Senior High School (45%). Algebra (45%) emerges as the dominant topic, followed by Geometry (18%) and Calculus (14%), indicating a strong emphasis on strengthening foundational mathematical concepts at the secondary level. In contrast, university-level research only accounts for 10%, highlighting a gap and potential opportunities for further exploration in higher education settings.

To foster a more comprehensive development of defragmentation research, future studies could aim to expand their scope by addressing underrepresented educational levels and exploring additional mathematical domains such as Measurement and Number Theory, which remain relatively unexplored in the current literature.

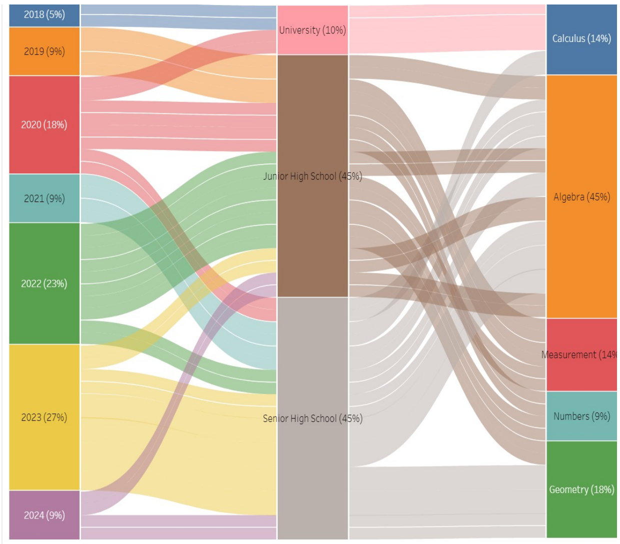

Fig. 3. Distribution of defragmenting research by year, education level, topic, and location.

B. What Types of Errors are Addressed in Defragmenting Research?

Defragmentation research in mathematical problem solving examines cognitive errors that hinder effective learning. These errors are identified through "auto checking", where students recognize their own mistakes, and "intervention checking", where external guidance helps address cognitive gaps [4]. Using open, axial, and selective coding, these errors are classified into several types.

Conceptual errors include "Conceptual Pseudofalse", which refers to errors that can be corrected through reflection, and "Conceptual Pseudotruth", where students provide answers that appear correct but are based on flawed reasoning, for instance, in a study by Wahab *et al.* [6], a student correctly determined the length of the hypotenuse of a triangle. However, the student believed that the two legs of a right triangle always have the same length an instance of a conceptual pseudotruth, where the reasoning process was fundamentally incorrect despite the final answer appearing correct.

Analytical errors, such as "Analytical Pseudotruth", occur when statements seem logically valid but lack deep understanding. "Analytical Pseudofalse" refers to reasoning that is initially incorrect but can be improved through further instruction or reflection. Lastly, "Misconceptual Errors" result from a fundamental misunderstanding of mathematical concepts, leading to systematic misapplications [7, 12]. These error types reveal the complexity of mathematical cognition and the necessity for tailored interventions to improve students' conceptual grasp. By identifying how errors emerge and whether they can be corrected through reflection or intervention, educators can design more effective strategies to support student learning. Addressing conceptual and analytical misconceptions through structured feedback and guided discovery may enhance problem-solving accuracy, fostering deeper comprehension of mathematical principles [13, 14]. A concise overview of these error types is summarized in Table I.

TABLE I. TYPES OF ERROR

Types of Errors	Description	Resource
Conseptual-Pseudotruth	A conceptual error in which the result appears correct, but the understanding or thought process behind it does not align with the actual concept.	[15, 16]
Conseptual-Pseudofalse	A conceptual error that is initially incorrect but can be corrected through deep reflection or learning intervention. Students have an initial misunderstanding but can correct it after receiving feedback or rethinking.	[15, 17–19]
Analitical-Pseudotruth	A statement or concept that appears analytically correct but is not based on deep understanding or accurate logic. This error is often accepted because it seems logical, but further analysis reveals the mistake.	[16, 20, 21]
Analitical-Pseudofalse	A thinking error that is initially incorrect but can be corrected with proper reflection or clarification. Students use logic that appears correct but is not entirely accurate, resulting in a mistaken conclusion. This error can be corrected after receiving further explanation.	[17, 18, 22, 23]
Misconseptual	A thinking error caused by misunderstanding or incomplete understanding of a basic concept. This leads to students not only misapplying the concept but also fundamentally misunderstanding it.	[6, 8, 9, 15, 16, 19, 23–29]
Misunderstanding	An error that arises from misinterpreting statements, instructions, or concepts, even though part of the material is understood correctly. This error stems from unclear information or incorrect assumptions made by students.	[6, 8, 9, 15–19, 22, 23, 25–29]
Inadverted Error	An error that occurs unintentionally or due to negligence, not from misunderstanding or conceptual errors. It is usually caused by external factors such as inattention, fatigue, or distractions during the process.	[8, 15–17, 26, 28]

C. How Are the Causes of Student Errors Diagnosed and Addressed through Defragmenting Interventions?

Defragmentation in mathematical research identifies and addresses student errors through diagnostic processes that reveal various cognitive barriers. One major cause of errors is low cognitive commitment, where students engage superficially in problem-solving, leading them to give up easily or rely on simplistic methods [17, 30]. Additionally, conceptual gaps arise when students struggle to connect previously learned concepts to broader contexts, requiring interventions that strengthen these connections [25]. Another common issue is conceptual fragmentation, where students' understanding is disjointed, preventing effective knowledge transfer and systematic problem-solving [31]. Defragmentation plays a crucial role in identifying and integrating these fragmented concepts through visual approaches and contextual applications [32].

Moreover, errors frequently stem from rote learning, where students rely on procedural memorization without grasping underlying principles, leading to incorrect application of concepts [33, 34]. Students who learn mechanically often perceive new problems as unfamiliar, even when they involve previously taught concepts, making adaptation difficult [23]. Defragmentation interventions address this by emphasizing deep understanding and encouraging students to explain both the concepts and reasoning behind their methods [35]. Additionally, the loss of control phase occurs when students lose track of the problem-solving steps, resulting in confusion and errors in comprehending problem components [36]. These interventions enhance students' problem management skills by promoting step-by-step, reflective problem-solving, ensuring they can think systematically and confidently when tackling mathematical problems [31]. The causes of these errors are systematically presented in Table II.

TABLE II. TYPES OF ERROR CAUSES

Types of Error Causes	Description	Resource
Cognitive Commitment	Students are not fully committed to the problem-solving process, resulting in a lack of focus and dedication to completing the task.	[8, 15, 17, 18, 22, 26]
Conceptual Gap	A gap in understanding that occurs because students have incomplete knowledge of the fundamental concepts they should master.	[9, 15, 17, 22, 23, 29, 37]
Conceptual Fragmentation	Fragmented understanding of concepts that leads to difficulties in connecting and applying mathematical concepts as a whole.	[6, 15, 17, 22, 23, 25–29, 37]
Learning by Rote	Learning that relies on memorization without deep understanding of the concepts, often leading to errors in concept application.	[16–18, 22, 23, 27, 37, 38]
Lose of Control Phase	Students lose control over their actions, thoughts, emotions, or problem-solving process, preventing them from continuing logical steps to reach a solution.	[8, 15–18, 21, 23–26, 28, 37]

D. What are the Types of Defragmenting Used?

Defragmentation in learning involves addressing cognitive errors by providing interventions that help students restructure their understanding and integrate concepts more deeply. Various types of scaffolding interventions, such as I-Scaffolding-Environmental Provisions, focus on creating a supportive learning environment that fosters collaboration and provides necessary resources, such as technology and visualization tools, to enhance students' engagement [32, 39]. For example, providing students with Geogebra on their smartphones enables a more interactive approach to problem-solving, promoting a deeper understanding [19]. This type of environmental scaffolding has been found to help students overcome challenges and enhance their problem-solving abilities [40].

Another important scaffolding intervention is I-Scaffolding-Reviewing, which involves prompting students to reflect on their problem-solving process to identify and correct errors in their thinking [32]. This process helps students reorganize their cognitive framework and recognize mistakes, thus fostering deeper conceptual understanding [41, 42]. Additionally, I-Scaffolding-Restructuring encourages students to view problems from different perspectives, facilitating better understanding of mathematical relationships [3]. This method often involves restructuring students' thinking by guiding them through questioning that helps them reorganize information in a more systematic manner, addressing fragmented thinking and improving problem-solving skills [20, 43].

Furthermore, cognitive conflict and disequilibrium interventions play a key role in defragmenting students' understanding. Cognitive conflict, by presenting students with contradictions in their reasoning, stimulates them to rethink their approach and correct errors [44]. Disequilibrium, on the other hand, induces discomfort by challenging existing knowledge structures, prompting students to adapt their thinking [6, 45]. These interventions, combined with scaffolding techniques, help to reduce cognitive load, allowing students to focus on deeper conceptual understanding, thus enhancing their overall learning experience [10, 11]. A classification of intervention types is provided in Table III.

TABLE III. TYPES OF INTERVENTION

Types of Intervention	Description	Resource
Scaffolding-Environmental Provisions	Interventions that modify or adjust the learning environment to support student engagement and better understanding. This involves the use of technology, collaborative spaces, or more relevant teaching materials.	[19]
Scaffolding-Reviewing	Providing students with opportunities to reflect on the steps they have taken in problem-solving, helping them recognize and correct errors in their thinking process.	[8, 15–19, 21–29, 37]
Scaffolding-Restructuring	Efforts to restructure students' understanding, helping them better see connections between concepts and reorganize their thinking to solve problems effectively.	[8, 9, 15–19, 21–29, 37]
Scaffolding-Explaining	Providing in-depth explanations or clear examples to help students understand difficult concepts or errors they have made, as well as why a particular step or solution is correct.	[8, 17–19, 21, 22, 25–27, 29]
Scaffolding-Developing Conceptual Thinking	Helping students develop conceptual thinking by encouraging them to see and understand fundamental concepts more deeply and connect them with other basic principles.	[19]
Cognitive Conflict	Engaging students in situations where their understanding conflicts with correct information or solutions, triggering further reflection and correcting their misconceptions.	[8, 9, 15, 17, 18, 21, 22, 25, 26, 29, 37]
Disequilibration	Creating imbalances in students' understanding to encourage them to adjust their knowledge structures, leading to deeper learning and more coherent understanding.	[6, 8, 15–18, 22–24, 26, 29, 37]

IV. Conclusion

Defragmentation of thinking structures can assist students in overcoming various types of errors encountered during mathematical problem-solving. This approach also enables the diagnosis of students' thinking errors and supports the design of intervention strategies that promote more guided and coherent problem-solving processes. However, most existing studies are limited to secondary education settings in Indonesia and predominantly focus on algebra-related topics. Minimal research has been conducted at the university level or in relation to technological integration.

To address these limitations, future research is encouraged to expand to higher education and underrepresented mathematical domains, such as measurement and number theory. The use of technology-based scaffolding tools (e.g., GeoGebra, intelligent tutoring systems) should also be explored. Furthermore, longitudinal studies are recommended to examine the long-term impact of defragmentation-based interventions on students' learning development.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Abdul Wahab A. contributed to conceptualization, methodology, data analysis, and original draft writing; Jarnawi Afghani Dahlan and Yaya S. Kusuma contributed to supervision, conceptual validation, and manuscript review; Syaiful contributed to translating the manuscript and editing; Mirza Aulia contributed to literature review, and data collection; all authors had approved the final version.

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