

Scaffolding in Mathematics Learning: A Literature Analysis of Its Impact on Conceptual Understanding

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Abstract

Conceptual understanding is a central objective of mathematics education; however, national and international reports consistently indicate that students' levels of conceptual understanding remain relatively low. One pedagogical approach widely recommended to address this issue is scaffolding, defined as the provision of gradual and temporary instructional support aligned with students' learning needs. This study aims to systematically examine empirical evidence on the implementation of scaffolding in mathematics learning and its impact on students' conceptual understanding through a systematic literature review. The study employed a systematic literature review (SLR) methodology. Relevant articles were retrieved from reputable academic databases, covering publications from 2020 to 2025. Seven selected studies were analyzed based on educational context, types of scaffolding, research design, and key findings related to mathematical conceptual understanding. Data were analyzed using thematic synthesis to identify recurring patterns, emerging trends, and existing research gaps. The findings indicate that scaffolding consistently exerts a positive effect on students' conceptual understanding of mathematics across different educational levels. Conceptual and metacognitive scaffolding were identified as the most effective forms, particularly in fostering relational understanding and deep mathematical reasoning. Furthermore, recent developments in technology-based and digital scaffolding demonstrate considerable potential for enhancing personalized learning, although their effectiveness largely depends on instructional design quality and appropriate fading strategies. This study concludes that while scaffolding is an effective instructional approach, it is inherently complex, underscoring the need for further longitudinal and integrative research to optimize its application in mathematics education.

Keywords: Scaffolding; Mathematics Learning; Conceptual Understanding.

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INTRODUCTION

Mathematics education plays a strategic role in developing logical, analytical, and problem-solving skills essential for the 21st century. Nevertheless, international assessments indicate that students' conceptual understanding of mathematics remains a global challenge. The Programme for International Student Assessment (PISA) 2022 reported a significant decline in average mathematics scores across OECD countries compared to previous cycles, with more than 30% of students failing to reach the basic proficiency level required to understand abstract mathematical concepts (OECD, 2023). These findings suggest that mathematics instruction has not yet sufficiently supported the development of deep conceptual understanding.

In response to this issue, pedagogical approaches emphasizing gradual and adaptive learning support have gained increasing attention. One such approach is scaffolding, which is grounded in Vygotsky's sociocultural theory of the Zone of Proximal Development (ZPD). Scaffolding refers to temporary instructional assistance provided by teachers or learning systems to enable students to achieve higher levels of understanding independently. Recent studies suggest that well-designed, adaptive scaffolding can significantly enhance conceptual understanding and knowledge transfer in mathematics learning (Bawadi et al., 2023).

Advances in educational technology have further influenced the implementation of scaffolding in mathematics education. The expansion of digital and blended learning environments in the post COVID-19 era has facilitated the emergence of computer-based scaffolding and intelligent tutoring systems. Empirical evidence indicates that technology-enhanced scaffolding can deliver more personalized and real-time feedback; however, its effectiveness is highly contingent upon instructional design quality and learner characteristics (Sun et al., 2024). This underscores that scaffolding is not a single instructional technique but rather a multifaceted pedagogical approach requiring careful design and evaluation.

Despite its potential benefits, the implementation of scaffolding in mathematics learning presents several challenges. Teachers often experience difficulty in determining the appropriate level and timing of support, as well as in implementing effective fading strategies. Additionally, student heterogeneity limits the effectiveness of generic scaffolding approaches in promoting equitable conceptual understanding. Prior research has also shown that excessively intensive scaffolding may inadvertently reduce students' learning autonomy (van de Pol et al., 2015).

Previous studies have documented the positive effects of scaffolding on mathematics learning outcomes, including increased student engagement and improved conceptual understanding. Effective scaffolding not only enhances understanding but also supports the



development of skills that contribute to improved mathematical performance (Doya, 2025). Instructional scaffolding has been shown to significantly improve secondary school students' mathematics achievement compared to traditional instructional methods, while also reducing gender-related achievement gaps (Nwoke, 2020). Similarly, Fildişi & Yildiz, (2025) reported that scaffolding promotes independent learning and problem-solving skills through temporary instructional support. However, its effectiveness varies across educational levels and mathematical sub-disciplines, highlighting the need for contextualized implementation.

A review of the existing literature reveals that many studies on scaffolding in mathematics education remain context-specific and focus on short-term interventions. Few studies systematically compare different types of scaffolding (such as conceptual, procedural, and metacognitive scaffolding) and their respective impacts on distinct dimensions of conceptual understanding. Moreover, existing literature reviews often fail to integrate findings from both face to face and digital learning contexts. These limitations point to the need for a more comprehensive and structured literature analysis.

Accordingly, a systematic literature review focusing on Scaffolding in Mathematics Learning: A Literature Analysis of Its Impact on Conceptual Understanding is both timely and necessary. This study seeks to synthesize recent empirical findings, identify patterns of scaffolding effectiveness, and provide a clearer conceptual framework for researchers and practitioners. In doing so, it aims to address existing gaps in the literature and contribute to the development of more effective and sustainable mathematics instructional practices.

RESEARCH METHOD

This study employed a systematic literature review (SLR) approach to comprehensively analyze empirical findings related to scaffolding in mathematics learning and its impact on students' conceptual understanding. The SLR approach was selected because it enables a transparent, structured, and replicable synthesis of existing research evidence, thereby facilitating the identification of research patterns, inconsistencies, and future directions. The review process began with the formulation of research questions focusing on: (1) the types of scaffolding implemented in mathematics learning, (2) educational contexts and levels, and (3) the impact of scaffolding on students' mathematical conceptual understanding. These questions guided the development of the search strategy and the determination of article selection criteria. Literature searches were conducted in reputable academic databases, including Google Scholar. The search keywords consisted of combinations of the terms "scaffolding," "mathematics learning,"



“conceptual understanding,” and “mathematics education.” To ensure relevance and novelty, the review was limited to peer-reviewed journal articles published between 2020 and 2025 and written in English.

The inclusion criteria comprised: (1) empirical studies or systematic reviews examining scaffolding in mathematics learning, (2) explicit measurement or discussion of conceptual understanding, and (3) research conducted in formal educational settings. The exclusion criteria included conceptual papers without empirical data, non peer reviewed conference proceedings, and studies focusing on subjects other than mathematics. Article selection was conducted through a stepwise screening process involving title, abstract, and full text review to minimize selection bias. Data analysis was carried out using thematic synthesis. Each selected article was coded according to the type of scaffolding employed (conceptual, procedural, metacognitive, or technology-based), research design, educational level, and principal findings related to conceptual understanding. To enhance the validity and reliability of the review, study quality appraisal was performed using methodological criteria commonly applied in educational research, such as clarity of research design, sample size adequacy, and appropriateness of data analysis techniques. The synthesized findings were presented narratively and supported by summary tables to highlight the contribution of each study and to identify remaining research gaps.

RESULT

The results of this study are based on a synthesis of seven scholarly articles published between 2020 and 2025 that investigated the implementation of scaffolding in mathematics learning and its impact on students’ conceptual understanding. The synthesis considered research objectives, educational contexts and levels, types of scaffolding applied, and key findings related to conceptual understanding.

Table 1. Summary of Findings from the Systematic Literature Review

No.	Author & Year	Context & Method	Type of Scaffolding	Key Findings
1	Basir & Wijayanti (2020)	Junior secondary school, empirical study	Procedural & Metacognitive	Scaffolding improves students’ mathematical reasoning and conceptual understanding.
2	Yumiarty et	Primary school,	ZPD-based scaffolding	Scaffolding implemented within



No.	Author & Year	Context & Method	Type of Scaffolding	Key Findings
	al., (2025)	experimental study		the Zone of Proximal Development significantly enhances students' conceptual understanding.
3	Saputra et al., (2024)	Primary–secondary education	Conceptual & Procedural	Scaffolding consistently enhances conceptual understanding and student engagement in mathematics learning.
4	Bawadi et al., (2023)	Secondary education	Conceptual	The positive effect of scaffolding on conceptual understanding is stronger than its effect on procedural fluency.
5	Azzaroiha et al., (2025)	Science & Mathematics	Conceptual	Scaffolding improves cross-disciplinary conceptual understanding.
6	Vo et al., (2025)	Systematic review	Conceptual & Procedural	Scaffolding promotes conceptual understanding through problem-solving activities.
7	Cohn et al., (2025)	Secondary school	Adaptive scaffolding integrating ECD, SCT, and ZPD theories	Human and AI collaboration provides effective adaptive scaffolding aligned with educational theories in STEM education.

Overall, the findings indicate that scaffolding consistently contributes positively to students' mathematical conceptual understanding across different educational levels, ranging from primary education to secondary and teacher education. However, the magnitude and nature of its effectiveness vary depending on instructional design, learning context, and student characteristics.

The reviewed studies demonstrate that conceptual and metacognitive scaffolding play a



particularly prominent role in supporting students' understanding of mathematical concepts. Early studies in the review period emphasized the importance of combining conceptual and procedural scaffolding to help students construct mathematical meaning in a gradual and structured manner (Basir & Wijayanti, 2020). More recent studies highlight a growing trend toward the integration of digital scaffolding and face to face instruction, grounded in the theoretical framework of the Zone of Proximal Development (Yumiarty et al., 2025).

Across the reviewed literature, conceptual scaffolding was found to exert a stronger influence on deep conceptual understanding than procedural scaffolding alone. Studies consistently report that scaffolding is most effective when designed to be contextual, adaptive, and oriented toward long term conceptual development rather than short-term task completion (Bawadi et al., 2023; Saputra et al., 2024).

DISCUSSION

The findings of this systematic literature review confirm that scaffolding is a pedagogical approach that consistently enhances students' conceptual understanding of mathematics across diverse educational contexts. These results align with constructivist learning theories, which posit that mathematical knowledge is actively constructed by learners through guided interaction, reflection, and problem solving rather than passively received. Scaffolding serves as a cognitive bridge that helps students move from their prior knowledge toward more complex mathematical concepts (Saputra et al., 2024; van de Pol et al., 2015).

Several studies emphasize the role of procedural and metacognitive scaffolding in improving students' reasoning and conceptual understanding, particularly at the secondary school level (Basir & Wijayanti, 2020). Metacognitive scaffolding, in particular, enhances students' awareness of their own thinking processes, enabling them to monitor, regulate, and evaluate their problem-solving strategies. From a cognitive perspective, this form of scaffolding strengthens learners' ability to internalize mathematical concepts and develop meaningful understanding.

Research adopting the ZPD framework further demonstrates that scaffolding designed in accordance with students' readiness levels significantly improves conceptual understanding, especially in primary education contexts (Yumiarty et al., 2025). These findings reinforce Vygotsky's assertion that learning is most effective when instructional support is provided just beyond students' current level of competence. In this regard, scaffolding functions as a conceptual bridge that enables students to internalize mathematical ideas that would otherwise remain inaccessible.



The reviewed literature also indicates that scaffolding contributes not only to cognitive outcomes but also to affective aspects of learning, such as student engagement. Saputra et al., (2024) report that conceptual and procedural scaffolding enhances both conceptual understanding and active participation in mathematics learning. When students perceive instructional support as structured and responsive, they are more likely to engage in discussion, exploration, and reflective thinking, thereby fostering deeper learning experiences.

A notable pattern emerging from the synthesis is that conceptual scaffolding exerts a stronger influence on conceptual understanding than procedural scaffolding alone. Conceptual scaffolding such as the use of guiding questions, visual representations, and explicit emphasis on relationships among concepts enables students to develop relational understanding rather than merely procedural fluency (Bawadi et al., 2023). This distinction is critical, as many difficulties in mathematics learning stem from an overemphasis on algorithmic procedures without sufficient attention to underlying meaning.

Furthermore, several studies extend the application of scaffolding beyond mathematics to interdisciplinary contexts, demonstrating its effectiveness in supporting conceptual understanding across domains (Azzaroiha et al., 2025). Systematic review evidence also confirms that scaffolding supports conceptual understanding through problem-solving activities, which serve as an important medium for higher-order thinking and knowledge construction (Vo et al., 2025).

Recent research on adaptive and technology-based scaffolding introduces new perspectives on personalized learning. Studies integrating human and AI collaboration and educational theories such as ECD, SCT, and ZPD indicate that adaptive scaffolding can dynamically adjust instructional support to meet individual learners' needs (Cohn et al., 2025). While these developments are promising, the literature emphasizes that the effectiveness of adaptive scaffolding depends heavily on instructional design quality and appropriate fading mechanisms.

Overall, the reviewed studies suggest that the effectiveness of scaffolding in mathematics learning is contingent upon the type of scaffolding employed, the instructional context, and student characteristics. Conceptual and metacognitive scaffolding appear to be more effective in fostering deep conceptual understanding than procedural scaffolding alone. These findings underscore the importance of designing scaffolding that prioritizes long-term conceptual development rather than short-term task performance.



CONCLUSION

Based on the findings of this systematic literature review covering publications from 2020 to 2025, it can be concluded that scaffolding is an effective instructional strategy for enhancing students' conceptual understanding of mathematics across various educational levels. The reviewed studies consistently demonstrate that scaffolding supports students in constructing mathematical understanding gradually, from basic conceptual knowledge to higher-order reasoning and knowledge transfer. The review further indicates that conceptual and metacognitive scaffolding have the strongest impact on conceptual understanding, as they enable students to comprehend not only how to solve mathematical problems but also why specific concepts and procedures are applied. Advances in educational technology have expanded the forms of scaffolding through adaptive and digital approaches, offering opportunities for personalized and real-time instructional support. However, the literature also cautions that poorly designed scaffolding may lead to learner dependency and hinder the development of autonomy. Overall, this study confirms that scaffolding is grounded in strong theoretical foundations and supported by consistent empirical evidence. By synthesizing existing research, this review identifies key patterns of effectiveness, implementation challenges, and research gaps, thereby contributing to the advancement of mathematics education research and practice.

RECOMMENDATIONS

Based on the findings and limitations of this review, several recommendations can be proposed. First, future research should conduct more in-depth comparative studies examining the effectiveness of different types of scaffolding (conceptual, procedural, and metacognitive) across various dimensions of mathematical conceptual understanding. Experimental or mixed-methods designs may provide clearer evidence regarding the most effective scaffolding strategies for specific educational levels and contexts.

Second, longitudinal studies are needed to examine the long-term effects of scaffolding on students' conceptual understanding and learning autonomy. Such studies would provide valuable insights into how scaffolding influences sustained learning outcomes beyond short-term interventions.

Finally, given the increasing integration of technology in education, further research should explore adaptive and AI-based scaffolding in mathematics learning, with particular attention to instructional design principles that balance learning support with gradual fading. Future studies in this area are expected to enrich the empirical evidence base and inform the development of more



effective, contextualized, and sustainable scaffolding models in mathematics education.

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