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Visualizing Research Trends on Instructional Scaffolding: A Science Mapping Study Based on Scopus Data

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ABSTRACT

This study maps the development of global research on instructional scaffolding using a science-mapping and bibliometric approach based on Scopus publications from 2000 to 2025. By employing VOSviewer to analyze keyword co-occurrence, author collaboration, citation patterns, and thematic evolution, the study unveils the intellectual structure and shifting priorities within the field. The results show that scaffolding research is anchored in core themes such as student learning, instructional design, cognitive support, and computer-aided instruction, while recent trends highlight the growing role of adaptive learning systems, artificial intelligence, and technology-enhanced pedagogies. Author network analyses reveal two dominant research communities: one focusing on cognitive and metacognitive scaffolding, and another emphasizing intelligent tutoring and automated support. The analysis of highly cited articles further emphasizes the multidisciplinary nature of scaffolding research, spanning computational thinking, STEM learning, writing instruction, and complex learning design. Overall, the findings provide a comprehensive overview of how instructional scaffolding has evolved, offering valuable insights for educators, researchers, and policymakers to guide future innovation in scaffolded learning environments.

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1. INTRODUCTION

Instructional scaffolding has become one of the most influential pedagogical constructs in contemporary learning theory, particularly in the shift from teacher-centered instruction toward more adaptive, learner-centered environments. Originally inspired by Vygotsky's concept of the Zone of Proximal Development (ZPD), scaffolding refers to the strategic support provided by educators, tools, or peers to help learners perform tasks they cannot yet accomplish independently [1]. Over the past four decades, the definition of scaffolding has expanded from guided interaction between teacher and learner to include metacognitive prompting, digital learning supports, automated feedback, and collaborative learning structures [2]. This conceptual evolution highlights the role of scaffolding as both a cognitive and socio-constructivist mechanism, making it central to the discourse on effective and meaningful instruction.

The rapid integration of technology in education has further transformed the way scaffolding is designed and delivered. Digital scaffolding—such as intelligent tutoring systems, adaptive feedback engines, augmented reality supports, and multimodal learning analytics—provides real-time assistance that can be customized to learners' needs [3]. These digital forms extend traditional scaffolding by offering immediate, dynamic, and scalable support across different learning environments. Consequently, research on scaffolding has spread into various subfields, including STEM education, literacy development, language learning, vocational training, and online learning. As the landscape of instructional technology grows more complex, scholars increasingly examine how scaffolding strategies can be personalized, automated, or embedded in digital ecosystems to optimize learning outcomes.

At the same time, the globalization of research and the diversification of educational settings contribute to new perspectives on scaffolding. Studies now examine scaffolding within multicultural classrooms, inclusive education, inquiry-based science instruction, and competency-based curricula [4]. The concept is not static; it adapts to pedagogical reforms, curriculum revisions, and socio-cultural expectations. As education systems worldwide attempt to address learning loss, digital divides, and rapidly changing skill requirements, scaffolding becomes an essential pedagogical tool to support learners' cognitive development, self-regulation, and problem-solving competencies. The theoretical and practical expansions in this field indicate the necessity to understand how scholarship on instructional scaffolding has evolved and where it is heading.

Despite its long history, research on scaffolding is highly fragmented across disciplines, methods, and educational contexts. Scholars adopt varied conceptualizations—ranging from cognitive scaffolds to procedural, strategic, or metacognitive scaffolds—creating divergent lines of inquiry and terminologies [5]. Furthermore, new research streams continue to emerge, such as scaffolding for computational thinking, project-based learning, and AI-supported adaptive instruction. These fragmented trajectories suggest the need for systematic mapping to reveal patterns, clusters, and intellectual structures underlying the field. Science mapping, particularly bibliometric and visualization-based techniques, provides powerful tools to uncover these structures and show how research communities interact, evolve, and influence one another over time.

Given the breadth and depth of the scaffolding literature, a comprehensive visualization of its development is essential to understand emerging trends and future research opportunities. Scopus, as one of the largest and most reliable scientific databases, offers extensive coverage of peer-reviewed publications, enabling robust and nuanced mapping of global research activity. By employing science-mapping tools such as VOSviewer and bibliometric techniques, researchers can identify influential authors, prominent journals, intellectual clusters, thematic shifts, and collaboration patterns. Making sense of these trends is not only academically valuable but also critical for policymakers, curriculum designers, educational technologists, and practitioners seeking evidence-based strategies to enhance instructional effectiveness.

Although research on instructional scaffolding has expanded remarkably across domains, there remains a lack of holistic understanding regarding how this field has developed, what intellectual structures underpin it, and which thematic trajectories dominate its evolution. Prior reviews often focus on specific contexts, such as literacy instruction, STEM learning, or online learning environments, without capturing the broader landscape of scaffolding scholarship. As a result, educators and researchers lack a comprehensive map that visualizes global research patterns, identifies emerging trends, and highlights conceptual gaps. Without such a science-mapping study, it becomes challenging to situate new research within existing knowledge, design more targeted interventions, or anticipate future developments in instructional scaffolding. This study aims to systematically visualize global research trends on instructional scaffolding using a science-mapping approach based on Scopus data.

2. METHOD

This study employed a science-mapping and bibliometric approach to analyze global research trends on instructional scaffolding. Bibliometric methods are widely used to uncover structural patterns in scientific literature, enabling researchers to visualize intellectual linkages, thematic clusters, and evolving research fronts across time. Science mapping was chosen because it provides a systematic and quantitative overview of knowledge development, complementing traditional narrative reviews by highlighting relationships among authors, keywords, journals, and citations. To ensure consistency and reliability, the study followed established bibliometric procedures, including data retrieval, cleaning, normalization, and visualization.

The dataset was retrieved from the Scopus database, selected for its comprehensive coverage of peer-reviewed articles, conference papers, book chapters, and reviews across education, psychology, and interdisciplinary fields. The search strategy used a combination of controlled terms related to "instructional scaffolding," including variations such as scaffolding instruction, educational scaffolding, learning scaffolds, and pedagogical scaffolding. Boolean operators (e.g., "instructional scaffolding" OR "learning scaffolds" OR "educational scaffolding") were applied in the title, abstract, and keywords fields to maximize retrieval accuracy. The year coverage was restricted to 2000–2025 to capture both early conceptual development and recent advances in digital and adaptive scaffolding. After downloading the Scopus records in RIS and CSV formats, duplicate entries, incomplete metadata, and non-relevant documents were removed through manual screening, ensuring that only publications directly related to instructional scaffolding were included.

The cleaned dataset was then analyzed using VOSviewer, a powerful visualization tool for constructing bibliometric maps. Several types of analyses were conducted: (1) co-authorship analysis to examine collaboration networks among researchers and institutions; (2) co-citation analysis to identify foundational works and intellectual structures; (3) keyword co-occurrence analysis to discover dominant themes and emerging topics; and (4) source analysis to determine influential journals and publication outlets. Threshold values were applied to filter low-frequency nodes so that network maps emphasized the most significant patterns. The results were visualized through cluster maps, density maps, and overlay visualizations, allowing for interpretation of thematic evolution, research hotspots, and shifting scholarly attention within the field of instructional scaffolding from 2000 to 2025.

3. RESULTS AND DISCUSSION

3.1 Network Visualization

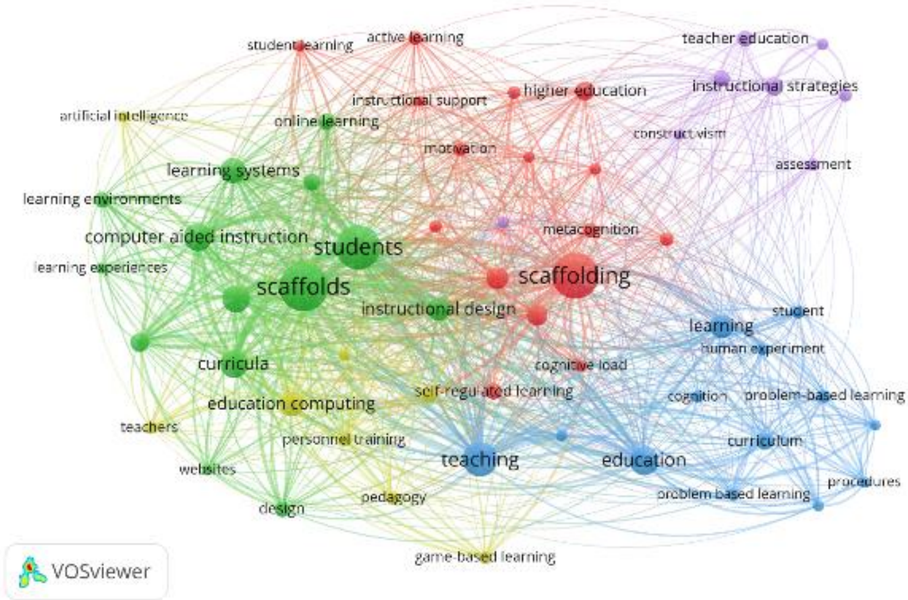

Figure 1. Network Visualization
Source: Data Analysis Result, 2025

The VOSviewer map illustrates a dense and interconnected landscape of research on instructional scaffolding, revealing four major thematic clusters that collectively describe the intellectual structure of the field. The red cluster, centered on terms such as scaffolding, higher education, metacognition, motivation, and student learning, reflects the pedagogical and psychological foundations of scaffolding, emphasizing how cognitive processes, learner autonomy, and instructional support interact to enhance academic performance. The green cluster highlights the strong influence of technology-enhanced learning, with keywords like students, learning systems, computer-aided instruction, learning environments, and artificial intelligence. This cluster shows the growing role of digital platforms, adaptive systems, and intelligent tools in providing automated and dynamic scaffolding. The blue cluster captures the intersection between scaffolding and instructional methodologies, containing terms such as teaching, education, problem-based learning, cognition, and learning outcomes, indicating that scaffolding is deeply integrated into inquiry-oriented and constructivist pedagogies. Meanwhile, the purple cluster, comprising instructional strategies, teacher education, and assessment, represents research streams focusing on teacher preparation, curriculum design, and pedagogical decision-making. The strong connections among clusters suggest that scaffolding research is inherently multidisciplinary—bridging technology, cognitive psychology, curriculum design, and higher education—while the prominence of nodes related to students, learning, and instructional design underscores the central role of learner-centered development within the broader landscape of educational innovation.

3.2 *Overlay Visualization*

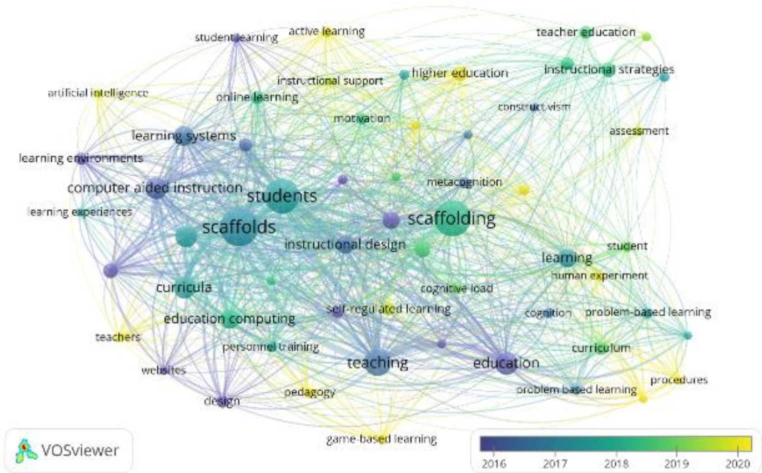

Figure 2. Overlay Visualization
Source: Data Analysis Result, 2025

The overlay visualization reveals the temporal evolution of research themes in instructional scaffolding, showing a gradual shift from foundational pedagogical topics toward more technologically oriented and data-driven themes. Earlier research (indicated by darker blue nodes, around 2016–2017) concentrated on traditional educational constructs such as teaching, education, curricula, learning environments, and computer-aided instruction. These themes reflect the early focus on classroom-based scaffolding, instructional design, and teacher-led approaches. As the colors transition into green and yellow (2018–2020), the network highlights emerging interests in active learning, online learning, assessment, higher education, and self-regulated learning, signaling the field's response to the rapid growth of digital learning ecosystems and the need to support learner autonomy. The prominent appearance of nodes like artificial intelligence, learning systems, and game-based learning in bright yellow suggests that recent studies increasingly explore AI-enhanced scaffolding, adaptive learning systems, and interactive digital environments. This temporal progression illustrates how scaffolding research has evolved from foundational theories of learner support to sophisticated, technology-embedded strategies that reflect the digital transformation of education.

3.3 *Citation Analysis*

Table 1. Most Cited Article

Citations	Author and Year	Title
1021	[6]	Review on teaching and learning of computational thinking through programming: What is next for K-12?
716	[7]	Augmented reality for STEM learning: A systematic review
632	[8]	Taking the load off a learner's mind: Instructional design for complex learning
621	[9]	A meta-analysis of writing instruction for students in the elementary grades
574	[10]	Supporting students' construction of scientific explanations by fading scaffolds in instructional materials
514	[11]	Augmented reality teaching and learning

Citations	Author and Year	Title
471	[12]	Designing for Productive Failure
375	[13]	Does adaptive scaffolding facilitate students' ability to regulate their learning with hypermedia?
352	[14]	Learning design to support student-AI collaboration: perspectives of leading teachers for AI in education
334	[15]	A conceptual framework for scaffolding III-structured problem-solving processes using question prompts and peer interactions

Source: Scopus, 2025

Table 1 highlights the most influential publications shaping the instructional scaffolding research landscape, as indicated by their citation counts in Scopus up to 2025. The highest-impact article, with 1021 citations, is the review by [6] on computational thinking in K–12 education, demonstrating how programming-based learning frameworks have become central to contemporary educational innovation. The next highly cited work, with 716 citations, is a systematic review by [7] on augmented reality for STEM learning, reflecting the rapid expansion of immersive technologies as scaffolding tools in complex instructional environments. Another foundational contribution, cited 632 times, is the article by [8], which emphasizes cognitive load management and instructional design for complex learning—core principles that underpin much of the scaffolding literature. The second section of the table continues to show strong citation patterns for meta-analyses and technology-oriented studies, including [9] meta-analysis of writing instruction (621 citations) and [10] work on fading scaffolds for scientific explanations (574 citations). Notably, [13] article on adaptive scaffolding also appears with 375 citations, underscoring the significance of adaptive, data-driven supports in digital learning environments. Collectively, the table illustrates that the most influential research spans three dominant themes: (1) technology-enhanced and immersive learning environments, (2) cognitive and instructional design principles for complex learning, and (3) evidence-based scaffolding strategies that support student regulation, explanation, and problem-solving. These highly cited works represent the intellectual anchors of the field and continue to guide emerging research on scaffolding in both traditional and digital educational contexts.

3.4 Density Visualization

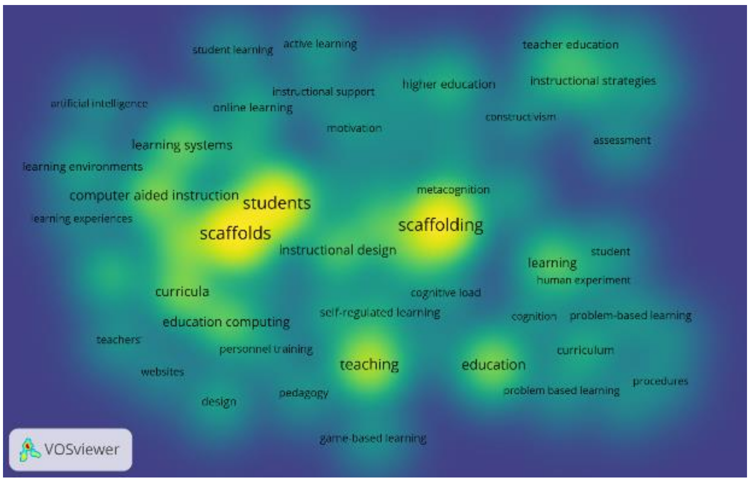

Figure 3. Density Visualization
Source: Data Analysis Result, 2025

The density visualization highlights the areas of highest research concentration within the instructional scaffolding literature, revealing several dominant thematic hotspots. The brightest yellow regions—representing the highest publication density—appear around the keywords students, scaffolds, and scaffolding, indicating that these terms form the conceptual core of the field and are most frequently explored in relation to learner support and performance. Surrounding these central nodes are moderately dense green areas such as computer-aided instruction, instructional design, learning systems, learning, and teaching, suggesting that significant scholarly attention is also directed toward understanding how scaffolding interacts with technology-enhanced learning environments, instructional planning, and pedagogical practices. The blue-green periphery shows less intensive but emerging themes, including artificial intelligence, game-based learning, teacher education, and problem-based learning, which reflect developing research interests that complement the core scaffolding discourse. Overall, the density map illustrates a research landscape that is heavily centered on learner-oriented scaffolding strategies while simultaneously expanding toward digital, cognitive, and pedagogical innovation.

3.5 *Co-Authorship Network*

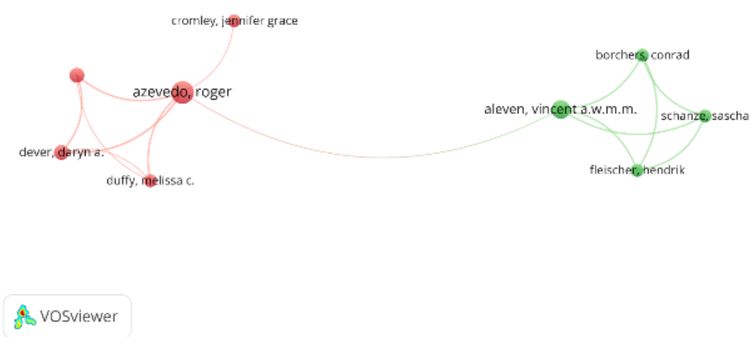

Figure 4. Author Visualization
Source: Data Analysis Result, 2025

The co-authorship network reveals two distinct clusters of influential scholars in the instructional scaffolding research domain, indicating the presence of separate yet complementary research communities. The first cluster, represented in red, is anchored by Roger Azevedo, a prominent figure known for his work on self-regulated learning, metacognitive scaffolding, and advanced learning technologies. His close collaborations with researchers such as Melissa C. Duffy, Jennifer Grace Cromley, and Daryn A. Dever reflect a strong focus on cognitive processes, learner regulation, and adaptive support systems. The second cluster, shown in green, centers on Vincent A.W.M.M. Aleven, whose research emphasizes intelligent tutoring systems, computer-based scaffolding, and student modeling. Aleven's collaborative network—comprising Conrad Borchers, Sascha Schanze, and Hendrik Fleischer—suggests a strong orientation toward technology-enhanced learning environments and automated instructional support. The two clusters are loosely connected through a weak bridging link, indicating occasional cross-disciplinary overlap but generally independent lines of inquiry. Overall, this structure highlights the dual foundations of scaffolding research: one rooted in cognitive and metacognitive support, and the other in AI-driven and computer-assisted instructional technologies.

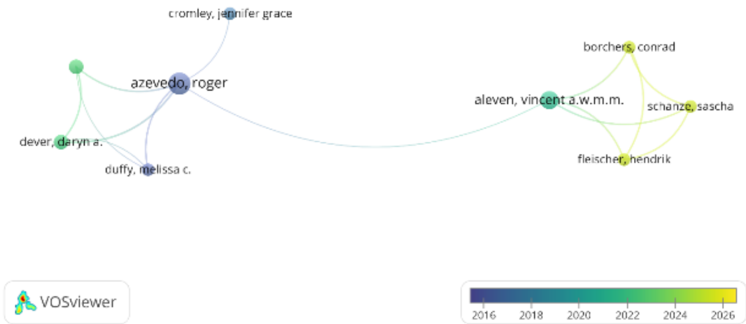

Figure 5. Affiliation Visualization
Source: Data Analysis Result, 2025

The overlay visualization of the author co-authorship network highlights the temporal progression of scholarly collaborations within the instructional scaffolding research community. The color gradient—from darker blue (earlier publications around 2016–2018) to bright yellow (more recent work around 2023–2025)—reveals two major research clusters and how their contributions have evolved over time. The first cluster, anchored by Roger Azevedo, shows early foundational work that has significantly influenced the field, as indicated by the darker blue tones around his node and those of colleagues such as Melissa C. Duffy and Jennifer Grace Cromley. This group's earlier contributions revolve around metacognition, self-regulated learning, and the cognitive mechanisms underlying scaffolding. In contrast, the second cluster led by Vincent A.W.M.M. Aleven displays more recent activity, with co-authors Conrad Borchers, Sascha Schanze, and Hendrik Fleischer appearing in green to yellow tones, reflecting intensifying research efforts in recent years. This emerging cluster is heavily oriented toward intelligent tutoring systems, automated scaffolding, and AI-driven learning environments. The visualization also shows a thin but meaningful connecting link between Azevedo and Aleven, indicating occasional cross-group collaboration while still maintaining distinct research trajectories. Overall, the overlay map demonstrates a shift from earlier cognitively oriented research toward newer, technology-enhanced and data-driven scaffolding innovations.

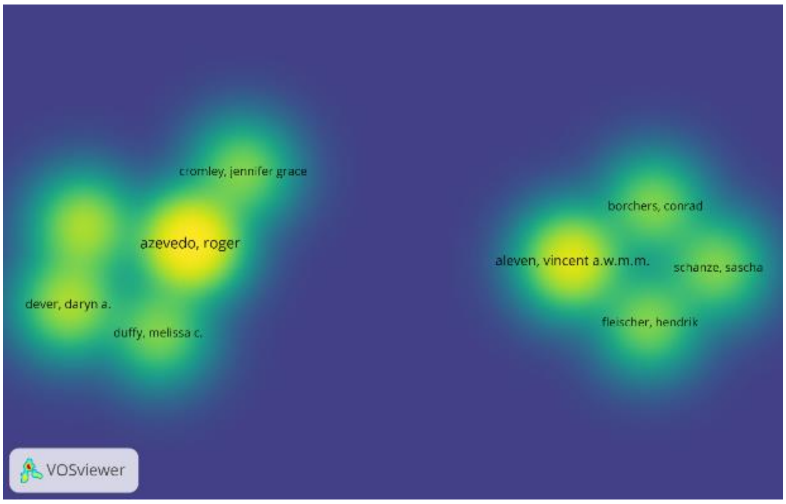

Figure 6. Country Visualization
Source: Data Analysis Result, 2025

The density visualization of author contributions reveals two prominent research hubs within the instructional scaffolding literature, each representing concentrated scholarly activity and influence. The left cluster, led by Roger Azevedo, shows the brightest density regions, indicating high productivity and strong citation presence within this author group. Surrounding Azevedo are frequent collaborators such as Jennifer Grace Cromley, Daryn A. Dever, and Melissa C. Duffy, suggesting a cohesive research community heavily focused on metacognition, self-regulated learning, and cognitive scaffolding processes. On the right side of the map, a second dense cluster forms around Vincent A.W.M.M. Aleven, whose work anchors a network of researchers including Conrad Borchers, Sascha Schanze, and Hendrik Fleischer. This group's bright density zones indicate a more recent but rapidly growing influence, particularly in intelligent tutoring systems, adaptive technologies, and computer-based scaffolding. The clear spatial separation between the two clusters suggests that scaffolding scholarship is driven by two strong but distinct intellectual traditions—one grounded in cognitive science and learner regulation, and the other rooted in AI-enhanced instructional support—while the intensity of the density areas reflects the central role these authors play in shaping global research directions.

3.6 Discussion

a. Practical Implications

The findings of this science-mapping study provide several practical implications for educators, instructional designers, and educational institutions. First, the prominence of keywords such as students, learning systems, computer-aided instruction, and self-regulated learning highlights the growing importance of integrating adaptive digital tools into classroom practice. Educators can leverage emerging technologies—including intelligent tutoring systems, AI-based feedback, and immersive learning environments—to create more personalized scaffolding that supports learner autonomy and metacognitive growth. Second, the clustering of research around instructional design, curricula, and teacher education suggests that professional development programs must emphasize scaffolded instructional planning, particularly in inquiry-based and problem-based learning contexts. Teachers need structured training on how to fade scaffolds progressively, diagnose learner needs, and select the appropriate type of support at different stages of learning. Third, the shift toward technology-enhanced scaffolding, especially in recent years, calls for institutions to invest in digital infrastructure and learning technologies that enable scalable support across diverse instructional settings, including online and hybrid classrooms. Policymakers and curriculum developers can use these insights to design education strategies that balance cognitive, pedagogical, and technological considerations to maximize student learning outcomes.

b. Theoritical Implications

The results also yield important theoretical contributions to the field of instructional scaffolding. The co-occurrence and density maps demonstrate that scaffolding research is grounded in two major theoretical traditions: (1) cognitive and metacognitive support frameworks, and (2) AI-driven and technology-enhanced learning theories. The separation of author clusters—centered around Azevedo and Aleven—reinforces the existence of these dual knowledge foundations. This duality suggests a growing need for integrative theoretical models that bridge human-centered cognitive scaffolding with machine-mediated adaptive scaffolding. Furthermore, the temporal overlay reveals the evolution from foundational constructivist perspectives toward dynamic, data-driven scaffolding models, indicating that existing theories such as the Zone of Proximal Development (ZPD), cognitive load theory, and self-regulated learning frameworks may require reinterpretation in the context of automated and real-time support systems. The strong presence of keywords like metacognition, motivation, instructional strategies, and problem-based learning suggests that future theoretical work should explore how cognitive, emotional, and social scaffolds interact within digitally mediated environments. Overall, this mapping study contributes to theoretical refinement by highlighting conceptual convergence across cognitive science, learning analytics, and educational technology.

c. Limitations

Despite offering comprehensive insights, this study carries several limitations inherent to bibliometric and science-mapping methods. First, the analysis relied solely on the Scopus database, which, although extensive, does not include all global publications; articles indexed exclusively in Web of Science, ERIC, Google Scholar, or non-indexed regional journals may not be captured. Consequently, the results reflect only the subset of literature visible within Scopus. Second, keyword co-occurrence and author collaboration networks depend heavily on metadata quality; inconsistencies in keyword labeling, author name variations, and incomplete indexing may influence the formation of clusters. Third, bibliometric maps emphasize frequency and connectivity rather than depth, meaning that highly cited works are highlighted even if their methodological quality or practical relevance varies. Additionally, the overlay visualization captures temporal trends only based on average publication year, which may mask intra-year developments or rapid thematic shifts. Finally, this study focuses on patterns rather than content-level interpretation; it does not analyze the full text of articles, leaving detailed qualitative examination of scaffolding strategies, theoretical nuances, and pedagogical outcomes for future research.

4. CONCLUSION

This science-mapping study provides a comprehensive picture of how research on instructional scaffolding has evolved from 2000 to 2025, revealing the field's intellectual foundations, thematic patterns, and emerging directions. The analysis shows that scaffolding scholarship is anchored in core themes such as student learning, instructional design, cognitive support, and computer-aided instruction, while more recent work increasingly incorporates digital technologies, AI-driven tools, and adaptive learning systems. The author and keyword networks highlight two major knowledge traditions—cognitive and metacognitive scaffolding on one side, and technology-enhanced, intelligent tutoring approaches on the other—each contributing distinct yet complementary insights to the broader field. Highly cited publications further indicate that impactful research spans diverse contexts, from computational thinking and complex learning to augmented reality and adaptive hypermedia scaffolding. Together, these findings suggest that instructional scaffolding has transformed into a multidimensional area that integrates pedagogy, technology, and cognitive science. Although the study is limited by its reliance on Scopus data and metadata constraints, it offers valuable guidance for future research and practice by identifying dominant themes, influential scholars, and promising new directions in the design and implementation of scaffolded learning environments.

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