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Algebraic Thinking in Problem-Solving: A Bibliometric Analysis

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***Abstract*:**
Generalization and symbolic manipulation are fundamental components of algebraic thinking. Generalization is often regarded as the core of mathematics and a defining characteristic of problem-solving. Consequently, the use of problem-solving contexts has strong potential to enhance and develop individuals' algebraic thinking skills. Both algebraic thinking and problem-solving play a crucial role in determining success in solving mathematical problems. This study aims to map publication trends and detect research gaps in studies on algebraic thinking and problem-solving indexed in the Scopus database through a bibliometric analysis. The results indicate that between 2001 and 2021, only 35 Scopus-indexed articles explicitly addressed algebraic thinking and problem-solving. This study aims to fill gaps in the state of the art by conducting a bibliometric review of these 35 articles. The findings reveal that algebraic thinking and problem-solving remain prominent and relevant research topics in mathematics education. Based on the bibliometric analysis, the term belief shows a relatively low occurrence, while self-efficacy does not appear among the keywords forming the main clusters or observable research trends related to algebraic thinking and problem-solving. Moreover, studies integrating algebraic thinking, problem-solving, scaffolding, and self-efficacy are still limited. Therefore, a promising direction for future research is to explore algebraic thinking processes through problem-solving scaffolding based on levels of student's self-efficacy.

Keywords: Algebraic Thinking, Problem-Solving, Bibliometric Analysis

Introduction

Algebra is a crucial subject for individuals, as it can foster a deeper understanding of mathematics and science. It can also be considered a potential source of future success (Moses, 1995; Kaput, 1998, 2002). However, not many students successfully solve algebra-related mathematical problems. School curricula often introduce algebra procedurally and do not explore the student's process of solving algebraic problems. Consequently, students have a shallow understanding of algebra. For them, algebra is nothing more than mathematical symbols.

Algebraic thinking is the mental framework of algebra, so mastery of algebraic concepts can be fostered by developing algebraic thinking skills. Algebraic thinking emerges when individuals form generalizations from experiences with numbers and calculations, formalize ideas using meaningful symbols, and explore concepts of patterns and functions. The pattern approach can unify arithmetic and algebra and support students' efforts to examine important algebraic concepts, such as variables (Radford, 2014). According to Kieran (2004), the difficulties experienced by students at the beginning of learning algebra are caused by the separation between learning arithmetic and learning algebra. The five categories of algebraic thinking are (a) generalization and formulation of arithmetic operations, (b) manipulation and transformation of specific equation problems through inverse operations and primary syntax, (c) analysis of mathematical structures, (d) relations and functions, including numbers and letters, and (e) algebraic language and representation (NCTM, 2000; Radford, 2000; Schliemann et al., 2013; Stephens et al., 2015; Usiskin, 1999). Lins (1992) argues that algebraic thinking refers to the shift from real contexts to mathematical structures. This contrasts sharply with the current algebra learning process, which seems to emphasize symbols and rules.

Problem-solving skills are one way to develop algebraic thinking skills, using problem-solving strategies and exploring multiple approaches/solutions (Kriegler, 2007). Problem-solving is a crucial topic in the study of mathematics. Problem-solving, defined as performing non-routine tasks for which the solver is unaware of previously learned schemes or algorithms designed to solve them (see Schoenfeld, 1985, 1992b), is a crucial aspect of mathematics (Halmos, 1980) and of mathematics learning and teaching (Liljedahl et al., 2016). Algebraic thinking and problem-solving are closely linked by general mathematical skills and understanding. because "one must be able to see similar situations (where to apply them), and one must master general types of solutions, general schemes of proof or argument (what to apply). The generalizations, relationships, and interconnections underlying mathematics can be used to develop algebraic thinking (Krutetski, 1976; Polya, 1973; Windsor, 2010).

Empirical studies suggest that problem-solving–based instruction supports the development of algebraic thinking by engaging students in constructing and coordinating mathematical representations and schemata, enabling a shift from procedural manipulation toward relational understanding (Steele & Johanning, 2004). Longitudinal classroom research further indicates that problem-solving activities grounded in functional approaches encourage students to employ diverse strategies and mathematical resources, thereby fostering deeper conceptual understanding of algebraic relationships over time (Yerushalmy, 2000). Consistent with these findings, research conducted in the Indonesian context shows that problem-based learning has a positive effect on students' algebraic thinking abilities in solving mathematical problems, particularly by promoting active reasoning and conceptual engagement among junior secondary students (La Resi et al., 2019).

Although the importance of algebraic thinking and problem-solving has been well established, what remains insufficiently understood is how research on these two constructs has developed as a whole. Existing studies predominantly focus on empirical classroom interventions or theoretical discussions, while limited attention has been paid to systematically examining publication trends, dominant themes, and underexplored areas within this body of literature. Consequently, the overall structure of the research field, including potential gaps and future research directions, has not been clearly articulated.

To address this limitation, this study employs bibliometric analysis within a systematic mapping framework. Unlike narrative reviews, which rely heavily on subjective synthesis, bibliometric analysis enables an objective and reproducible examination of large volumes of publications by analyzing publication patterns, keyword co-occurrences, and thematic structures. Compared to meta-analysis, which focuses on effect sizes and comparable quantitative outcomes, bibliometric analysis is more appropriate for mapping research landscapes and identifying emerging or marginal themes across diverse study designs (Zupic & Čater, 2015). Therefore, this method is particularly suitable for capturing the intellectual structure and evolution of research on algebraic thinking and problem-solving.

Using the bibliometrix R package and its Biblioshiny interface (Aria & Cuccurullo, 2017; Secinaro et al., 2020), this study systematically analyzes Scopus-indexed publications from 2001 to 2021. Building on the theoretical background and the identified research gap, the present study is guided by the following research questions:

Q1: What is the scientific publication trend in the world of algebraic thinking in problem-solving field?

Q2: What are the future directions for research in this area?

Research Methods

This study employs a Systematic Mapping Study (SMS) supported by bibliometric analysis to map research on algebraic thinking and problem-solving. SMS was selected because it is suitable for examining broad research domains, identifying publication trends, thematic structures, and research gaps, rather than synthesizing empirical effects as in meta-analysis (Zupic & Čater, 2015).

The literature search was conducted using the Scopus database. Article selection was based on predefined keywords related to "algebraic thinking" and "problem-solving" and explicit inclusion criteria: (a) both constructs were central to the study as indicated in the title, abstract, or author keywords; (b) articles were peer-reviewed and written in English; and (c) publications appeared between 2001 and 2021. Titles and abstracts were screened to ensure relevance, resulting in 35 articles for analysis. Although the dataset is relatively small, it reflects the specificity of the research focus and is methodologically adequate for mapping thematic patterns within this domain.

Bibliometric analysis was conducted using the bibliometrix package in R Studio, with Biblioshiny used for data processing and visualization (Aria & Cuccurullo, 2017a). The SMS was operationalized through five phases: study design, data collection, data analysis, data visualization, and interpretation (Aria & Cuccurullo, 2017a; Cobo et al., 2011; S. Secinaro et al., 2020; Zupic & Čater, 2015). Performance analysis was used to examine publication trends addressing Q1, while science mapping techniques, including keyword co-occurrence and thematic analysis, were applied to explore research structures and future directions relevant to Q2. The overall workflow of the study is summarized in Figure 1.

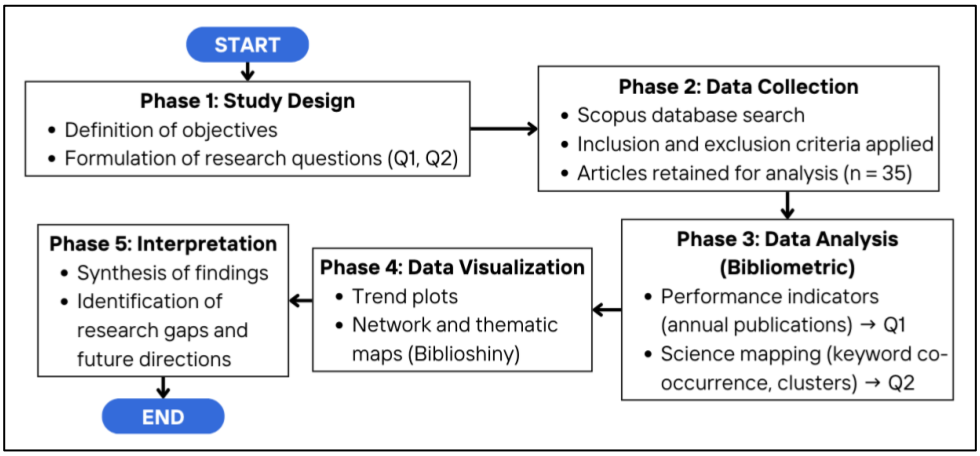


Figure 1. Overview of the Systematic Mapping and Bibliometric Analysis Process

Results and Discussions

Scientific Publication Trend in the World of Algebraic Thinking in Problem-Solving Field

The article selection process was conducted through the Scopus database with the keywords "algebraic thinking" and "problem-solving". Based on the 35 selected articles, a bibliometric analysis was conducted using R Studio. General information about the selected articles can be seen in Table 1.

Table 1 shows that research on algebraic thinking in problem-solving is a relatively focused area of literature, as indicated by the limited number of documents (35) spread across 26 sources. The average document age of 6.57 years and the annual growth rate of 7.18% may indicate a steady but moderate development of the field over time, rather than rapid expansion. The average number of citations per document (10.06) indicates a moderate level of scholarly attention, although the impact of citations appears uneven across publications. Authorship patterns indicate a predominance of works written by multiple authors, reflected in the low number of documents written by a single author and the co-authorship rate of 5.714%, suggesting that collaboration is present, while the relatively limited international co-authorship may imply that cross-national collaboration is less common. Furthermore, the larger number of author keywords compared to Keywords Plus may reflect conceptual breadth and variability in terminology, which may indicate that the thematic structure of this research field is still developing. Overall, these characteristics suggest that although research on algebraic thinking and problem-solving has received sustained attention, further consolidation and broader collaboration could contribute to the development of a more cohesive field.

Table 1. Main Information bout Algebraic Thinking and Problem-Solving

Description	Results
Documents	35
Sources	26
Document average age	6.57
Average citations per documents	10.06
Keyword plus (ID)	71
Author’s keywords (DE)	102
Authors	81
Authors of single-authored documents	11
Co-authors per documents	2.49
International co-authorship (%)	5.714
Annual growth rate (%)	7.18

Publication of articles on the topic of algebraic thinking and problem-solving began to increase from 2017 and peaked in 2018 with 5 articles (Figure 2). When viewed together, Figure 1 and Table 1 indicate that research on algebraic thinking in problem-solving exhibits discontinuous rather than sustained growth. The increase in publications after 2017 and its peak in 2018 is consistent with the limited number of papers (35) and moderate annual growth rate (7.18%), suggesting gradual development of the field. The fluctuating publication pattern indicates that research activity has not stabilized, indicating that this field is still a developing domain with potential for further research.

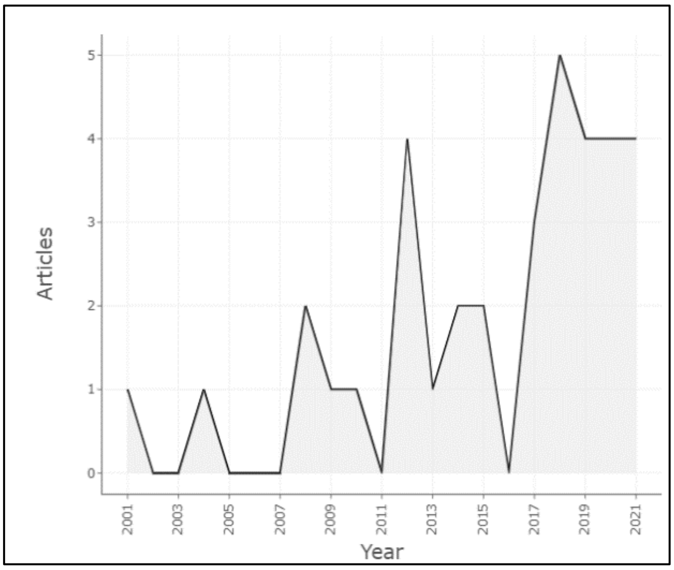


Figure 2. Annual Scientific Production

Corresponding authors are responsible for the content of the article and the legality of the article submission, as well as any article revisions. The eleven countries with the most corresponding authors are listed in Figure 3. The country of origin of the corresponding author that published the most articles in recent years is the United States with 8 articles (0.229%). Indonesia is in third place with 2 articles (0.053%). The country with the greatest scientific impact on the publication of articles on algebraic thinking and problem-solving is the United States. Its articles were cited 105 times, followed by Singapore with 71 citations. Indonesia is in fifth place in terms of the scientific impact of publication of articles on algebraic thinking, with 12 citations.

Based on Figure 3, the dominance of the United States as the country of origin of corresponding authors reflects not only a higher number of publications but also a robust research ecosystem supported by extensive international collaboration in the field of algebraic thinking and problem-solving. Indonesia's position among the top contributing countries demonstrates considerable research potential, but also reveals a significant gap compared to leading countries in terms of consistent productivity and integration into the global research community. The collaboration patterns shown in the figure indicate that some countries remain heavily reliant on publications produced within a single country, which can limit the visibility and long-term impact of their research. Figure 3 highlights the imbalance in global research leadership and underscores the importance for countries like Indonesia to expand international collaboration to improve research quality, increase scientific impact, and ensure the sustainability of contributions to the study of algebraic thinking.

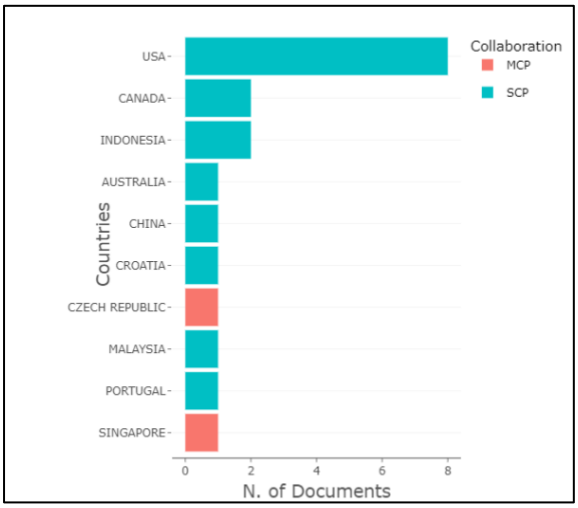


Figure 3. Corresponding Author's Country

The relationships between authors (AU), primary sources (CR), and keywords (DE) are represented in Figure 4. This visualization reveals a structured yet concentrated intellectual landscape in research on algebraic thinking in problem-solving. A limited number of fundamental references and authors act as central nodes connecting dominant themes. Key works such as those by Ma, Mason, Kaput, Cobb, Carpenter, and Kieran appear to have strongly influenced subsequent authors, suggesting that the field remains rooted in a relatively stable theoretical core. Thematically, the strongest relationships center on problem-solving, algebraic thinking, reasoning, and representation, suggesting that current research prioritizes cognitive processes over broader pedagogical, contextual, or sociocultural dimensions. This concentration implies both coherence and limitations: while it reflects a shared conceptual foundation that strengthens theoretical consistency, it also signals the risk of intellectual saturation and a lack of exploration of new perspectives, such as technology-mediated learning or interdisciplinary approaches.

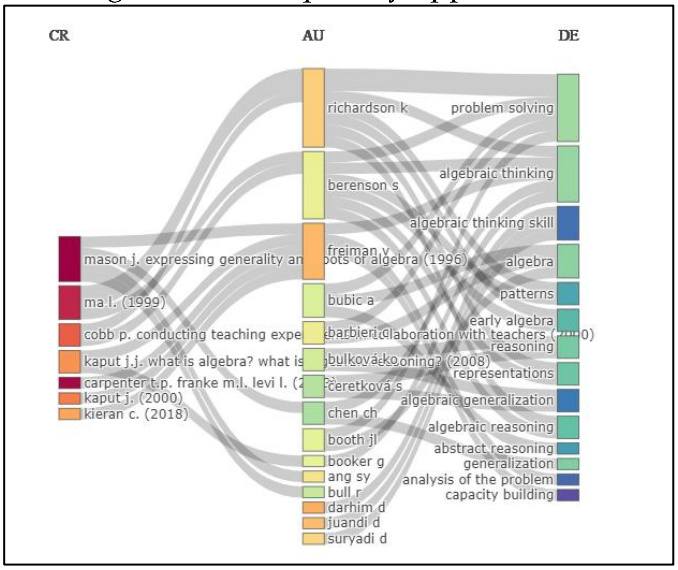
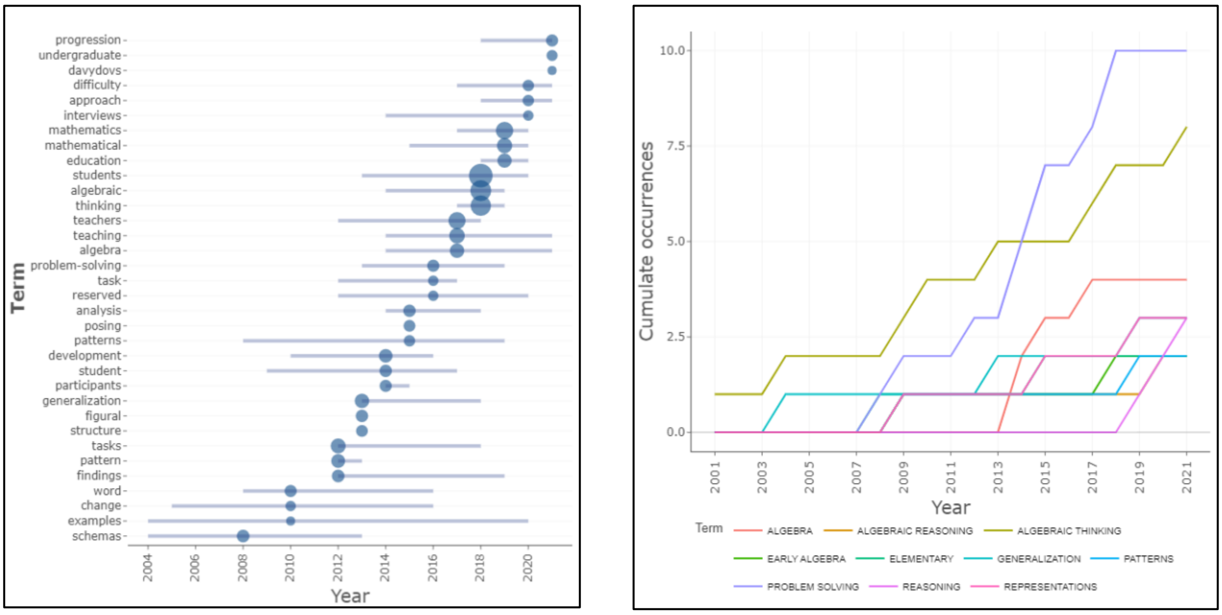


Figure 4. Three Field-Plot

Trends in algebraic thinking and problem-solving research topics can be seen based on abstracts and keywords. Figure 5(a) illustrates the temporal development of research topics in the study of algebraic thinking, revealing a gradual shift in conceptual and methodological focus over time. Early research largely addressed basic concepts such as schema, exemplar, and change, reflecting early attempts to build a theoretical understanding of algebraic structure. In later periods, attention increasingly shifted to cognitive processes, including patterns, generalizations, and structures, indicating a deeper interest in how mathematical thinking develops. More recent studies emphasize themes such as algebraic thinking, problem-solving, teaching, teachers, and students, indicating a stronger orientation toward educational practice and classroom contexts. However, the uneven temporal distribution and limited repetition of some key topics suggest that the field's evolution remains selective rather than fully integrated. Critically, this pattern implies that although research has progressed toward applied and pedagogical concerns, there remains a need to more frequently reconnect contemporary empirical studies with their underlying theoretical roots to ensure a coherent and sustainable development of research on algebraic thinking.

Figure 5(b) shows a clear shift in research priorities in the study of algebraic thinking over time, as reflected in the cumulative growth of key terms. Problem-solving shows the most pronounced and accelerated increase, particularly after the mid-2010s, indicating its emergence as the dominant analytical lens used to examine algebraic thinking today. Algebraic thinking and algebraic reasoning also show steady growth, indicating an interest in higher-order cognitive processes rather than the procedural aspects of algebra. In contrast, terms such as early algebra, representation, and patterning emerged later and grew more slowly, suggesting that the fundamental and representational dimensions have received relatively less sustained attention. This imbalance highlights a critical tension in the field: while research increasingly emphasizes advanced reasoning and problem-solving outcomes, it risks underdeveloping the fundamental pathways that shape such thinking. Consequently, the figure suggests that future research would benefit from a more balanced integration of early, representational, and reasoning-based perspectives to support a more coherent and developmentally grounded understanding of algebraic thinking.



(a) (b)

Figure 5. (a) Trends in Research Topics Based on Abstracts; (B) Trends in Research Topics Based on Keywords

Figure 6(a) represents a conceptual map of the research discourse on early algebra, which places algebra, generalization, reasoning, and representation as central pillars. Algebra is not merely a mathematical topic, but a fundamental way of thinking developed from the elementary grades. Substantially, the importance of generalization and reasoning signals a paradigm shift from procedural algebra instruction toward the development of structural thinking, where patterns, relationships, and multiple representations serve as bridges between children's concrete experiences and symbolic abstractions. The presence of terms such as patterns, algebraic thinking, concrete reasoning, and children's mathematical thinking underscores the view of early algebra as a developmental cognitive process rather than an advanced content area reserved for higher grades. Critically, the map also reveals tensions between conceptual, constructivist approaches and classroom realities, reflected in notions such as algebraic difficulty, error analysis, and instructional interventions. Overall, the figure goes beyond visual categorization to highlight the epistemological and pedagogical imperatives for elementary mathematics education to build meaningful, inclusive, and sustainable foundations for algebraic understanding, rather than focusing narrowly on symbolic manipulation.

Figure 6(b) visualizes the conceptual network structure of research on algebraic thinking in mathematics education, where students, algebraic thinking, mathematics, reasoning, and problem-solving emerge as dominant and highly interconnected nodes. Essentially, this structure suggests that algebra is viewed not as isolated symbolic content, but as a cognitive activity embedded in students' thinking processes and learning experiences. Analytically, the clustering reveals a strong alignment between pedagogical practices (instruction, tasks, classroom), cognitive dimensions (reasoning, understanding, development), and empirical orientations (study, data, outcomes, performance), indicating that research in this area is increasingly integrating learning theory with classroom-based evidence. Importantly, however, the separation of clusters such as those related to assessment outcomes (outcomes, tests, schools) and those focused on conceptual learning (reasoning, understanding, learning) reveals a persistent gap between evaluative practices and deeper understandings of algebra. This tension highlights challenges in education where algebraic thinking is important but narrow assessments often overlook students' deeper reasoning processes.

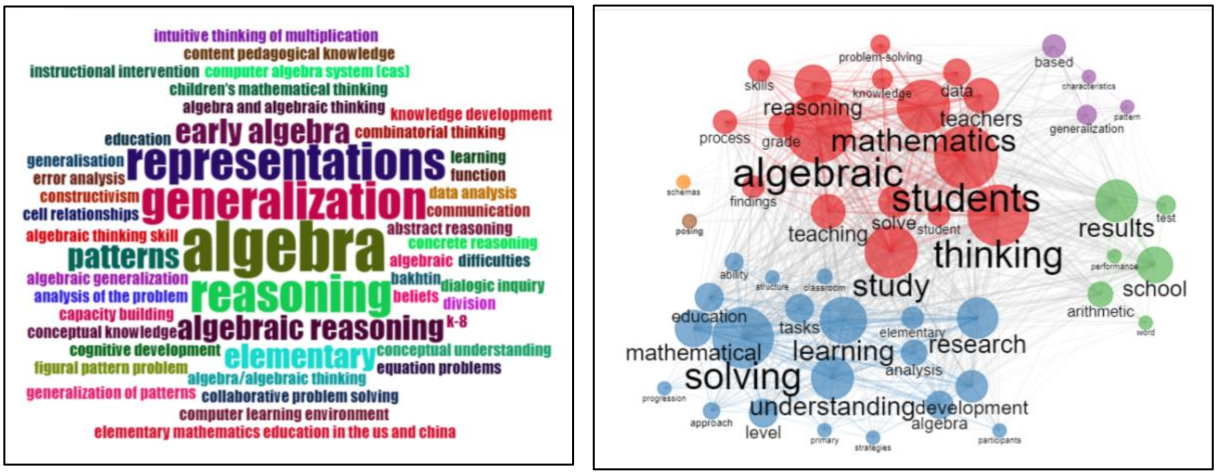


Figure 6. (a) Word Cloud based on Author's Keywords; (b) Co-occurrence Network based on Abstract

The clustering of article keywords based on their occurrence can be seen in Table 2. There are three clusters with the most occurrences for the keyword "problem-solving," which can be called motor themes. The "representations" cluster is a theme that appears in decreasing order.

Table 2. Clustering of Article Keywords based on Their Occurrence

Occurrence	Keyword	Cluster	Cluster Name
6	Algebraic thinking	1	Algebraic thinking
3	Generalization	1	Algebraic thinking
3	Reasoning	1	Algebraic thinking
2	Algebraic reasoning	1	Algebraic thinking
2	Early algebra	1	Algebraic thinking
2	Patterns	1	Algebraic thinking
10	Problem-solving	2	Problem-solving
4	Algebra	2	Problem-solving
2	Elementary	2	Problem-solving
3	Representations	3	Representations

Future Directions for Research in the Algebraic Thinking in Problem-Solving Field

The number of publications addressing algebraic thinking in problem-solving showed a gradual increase between 2001 and 2022, with a peak observed in 2018, marked by five published articles and a concomitant increase in citations. Rather than simply indicating a continuous research trend, this pattern indicates a period of increased scholarly attention, likely driven by a broader shift in mathematics education toward early algebra and cognitively oriented problem-solving. However, the uneven distribution of publications across years also suggests that research interest in this area may be episodic and influenced by contextual factors, underscoring the need for a more in-depth analysis of thematic continuity and research impact beyond publication frequency alone.

Kieran (1996) stated that algebraic thinking is not simply about symbols to express generalities, but rather occurs when individuals use any type of representation when attempting to manipulate quantitative situations in a relational manner. Driscoll (1999) stated that algebraic thinking can be thought of as "the capacity to represent quantitatively" situations so that the relationships between variables become clear. Ralston illustrates the algebraic thinking framework in Figure 7, adapted from Kaput's algebraic thinking framework.

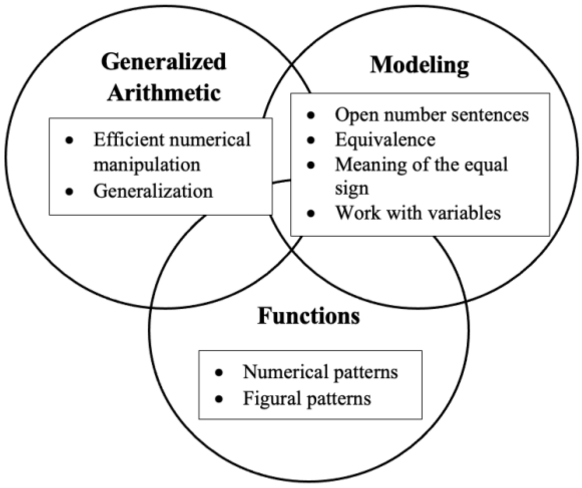


Figure 7. Raslton's Algebraic Thinking Framework (2013)

The use of problem-solving contexts has the potential to expand and develop students' mathematical thinking and abstraction in understanding more complex problems (Kaput, 2008; Kaput, Blanton, & Moreno, 2008; Schliemann, Carraher, & Brizuela, 2007; Lins, Rojano, Bell, & Sutherland, 2001). Algebraic thinking and problem-solving are closely related by general mathematical skills and understanding. because "one must be able to see similar situations (where to apply them), and one must master general types of solutions, general schemes of proofs or arguments (what to apply). The generalizations, relationships, and interconnections underlying mathematics can be carried over to the development of algebraic thinking (Krutetski, 1976; Polya, 1973; Windsor, 2010).

Based on the thematic network analysis, the keywords "algebraic thinking" and "problem-solving" emerged as the most dominant and were sometimes linked to the keyword "beliefs." While the presence of beliefs suggests a new area of research in the literature, their relatively limited frequency suggests that this construct has not been extensively explored in relation to algebraic problemsolving. Rather than positioning self-efficacy as the primary explanatory framework, bibliometric findings point to beliefs as a peripheral but potentially significant theme that warrants further empirical investigation. Previous studies have established that students' beliefs, including self-efficacy, can influence mathematics learning and problem-solving performance; however, the current mapping indicates that this psychological construct remains underrepresented in the existing research landscape, highlighting a gap rather than a dominant focus in this field. Bandura (2006: 307) defines self-efficacy as "beliefs in one's capability to organize and execute the courses of action required to manage prospective situations." Self-efficacy can influence mathematics achievement (Bandura, Barbaranelli, Caprara, & Pastorelli, 1996; Fast et al.; Pajares, 2005). In relation to problem-solving, self-efficacy functions as a tool to assess students' success in solving problem-solving problems (Bandura, 1996; Schoenfeld, 2006).

In mathematics education, scaffolding is commonly understood as a form of instructional support that assists learners in engaging with problem-solving and developing algebraic thinking. The term scaffolding did not emerge from the output of bibliometric analysis. This could be an opportunity for future researchers. Scaffolding is a technique for bridging the gap between a learner's current skill set and desired skill set by providing guidance to learners from knowledgeable sources, such as instructors and instructional designers (Kim & Hannafin, 2011). Scafolding is a fundamental component of constructivism-based pedagogies (Pea, 2004). Constructivism theorizes that people build knowledge by constructing it for themselves through integrating new information into existing knowledge structures, rather than by being told what to know (Vygotsky, 1978; Wood et al., 1976). Learners who have limited prior Knowledge, however, will require instructional support to build knowledge and reduce foundational learning (Hmelo-Silver et al., 2007; Schmidt et al., 2007). Much current research on constructivist-based learning environments is devoted to exploring the appropriate types and amounts of guidance, including scaffolding, to support learning (Tobias & Dufy, 2009).

Based on bibliometric findings, research on algebraic thinking and problem-solving has largely focused on cognitive processes and instructional approaches, while affective factors such as beliefs and instructional support appear less prominent. This analysis does not support the claim that these themes represent the current state of the art. Rather, their limited presence suggests potential avenues for future research. Consequently, further empirical research is needed to examine how instructional support and students' beliefs in mathematics may interact with algebraic thinking processes in problem-solving contexts, without presuming their centrality or effectiveness in the existing literature.

Conclusions and Suggestions

The bibliometric analysis indicates a continued growth of publications on algebraic thinking and problem-solving through 2021. Most research focuses on cognitive dimensions, student learning processes, and classroom-based problem-solving practices. Thematic mapping reveals that algebraic thinking and problem-solving are core themes in this field, while affective constructs such as beliefs or self-efficacy appear marginal and underdeveloped. This mapping contributes to the literature by clarifying not only dominant research directions but also underexplored areas that require further investigation.

In this context, existing studies generally position problem-solving as a means to foster algebraic thinking, particularly among junior high school students. However, the limited attention to learner-related factors suggests opportunities for future research to examine how affective variables, such as beliefs, may interact with algebraic thinking processes. Rather than defining the current state of the art, these perspectives emerge as potential research directions that could expand the field by addressing populations and educational levels that remain underrepresented in the existing literature.

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