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MAPPING THE INTELLECTUAL LANDSCAPE OF PRIMARY SCIENCE EDUCATION

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Abstract. *Background: Primary science education is critical for developing scientific literacy and fostering long-term interest in STEM. However, implementation faces challenges such as limited teacher preparation, rigid curricula, and unequal digital access. Purpose: This study aims to map the intellectual structure and emerging trends in primary science education research using a bibliometric approach. Method: A total of 2,295 publications from the Web of Science database were analyzed using VOSviewer. Bibliographic coupling and co-word analyses were conducted to identify influential publications, thematic clusters, and evolving research patterns. Results: Five main thematic clusters emerged: (1) technology-enhanced instruction using augmented and virtual reality, (2) equity and teacher competence in science achievement, (3) cognitive and metacognitive scaffolds, (4) dialogic and integrative pedagogies, and (5) computational thinking in STEM. The findings indicate a shift toward student-centered and digitally mediated pedagogies. However, gaps remain in culturally responsive computational thinking and understanding teacher identity in reform efforts. Conclusion: This study offers a comprehensive overview of primary science education research, highlighting key areas of progress and remaining challenges. It underscores the need for inclusive digital integration, culturally responsive teaching, and interdisciplinary frameworks. Future studies should expand database coverage for a more global perspective.*

Keywords: *science education, primary schools, bibliometric analysis, education policy*

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Introduction

Science education at the primary level, which refers to the initial years of formal schooling and typically includes children aged 5 to 12, plays a vital role in supporting intellectual development. It fosters curiosity (Lindholm, 2018), promotes critical thinking (Vieira & Tenreiro-Vieira, 2016), and supports the development of lifelong learning competencies (Letina, 2020). As the world becomes increasingly shaped by scientific and technological advancements, early engagement with scientific concepts is essential for enhancing students' cognitive skills and stimulating interest in STEM disciplines, which are vital to national innovation and economic progress (Jia et al., 2024).

Although there has been growing advocacy for interactive and inquiry-based approaches that emphasize hands-on engagement and student-centered learning (Van Uum et al., 2017; Jumayeva, 2021), several persistent challenges have hindered their effective implementation. Researchers have highlighted issues such as limited instructional resources, inadequate teacher preparation, and rigid curricular structures as major obstacles (Kohler & Dietrich, 2021; Rogan & Grayson, 2003; Symaco & Daniel, 2018). These barriers restrict the application of active learning methodologies and reduce opportunities for students to meaningfully engage with scientific content.

Scholars have examined diverse educational strategies, classroom challenges, and innovations in science pedagogy; however, a comprehensive bibliometric analysis focused specifically on primary science education has been lacking. Previous bibliometric studies have addressed broader topics, including scientific literacy, STEM education, and critical thinking (Aktoprak & Hursen, 2022; Jamali et al., 2023; Kutlu-Abu et al., 2023), but they have not systematically mapped the intellectual and thematic developments unique to the primary level. Given the critical role of early science education, synthesizing existing research through bibliometric techniques is crucial for informing future inquiries and educational practices.

Despite increased interest in reform-oriented science education, the academic understanding of primary-level science teaching remains fragmented. Research has often been compartmentalized into subtopics such as inquiry-based learning, teacher professional development, STEM

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integration, and digital pedagogies. While these individual studies have offered valuable insights, the field lacks a systematic analysis that captures its intellectual evolution and thematic directions. This absence hinders educators, researchers, and policymakers from accessing a holistic understanding of research trends and limits their ability to make evidence-informed decisions. A bibliometric synthesis is therefore necessary to consolidate fragmented knowledge, identify emerging areas, and guide coherent instructional and policy innovations in primary science education.

Research Focus

This study concentrates on the landscape of science education at the primary level by examining published academic literature through bibliometric techniques. Specifically, it focuses on how scientific inquiry into primary science education has evolved over time, what thematic areas dominate the field, and which conceptual frameworks and scholarly voices are shaping discourse. Through bibliographic coupling and co-word analysis, this research seeks to reveal both well-established domains and emergent fields of interest, highlighting knowledge gaps, scholarly networks, and thematic convergence or divergence. The study targets publications indexed in the Web of Science database to ensure rigor and breadth.

Literature Review

The evolution of science education in primary schools has been shaped by diverse philosophical, psychological, and pedagogical paradigms. Early foundations were laid by John Dewey, whose advocacy for experiential learning in the early 20th century emphasized the role of inquiry and reflection in the educational process (Kraft, 1990; Ord, 2012). Dewey's progressive ideals catalyzed the development of constructivist theories, notably advanced by Piaget and Vygotsky, who posited that children actively construct knowledge through social interaction and experiential engagement (Devi, 2019; Hein, 1991). These theoretical contributions laid the groundwork for modern inquiry-based learning approaches that are now integral to primary science instruction.

The publication of the National Science Education Standards (National Research Council [NRC], 1996) marked a pivotal moment in institutionalizing inquiry-based science education. These standards promoted a shift from rote memorization to active exploration, urging educators to foster scientific reasoning and process skills among young learners. Subsequent empirical studies have further supported the efficacy of inquiry-based strategies in promoting deeper understanding and long-term retention of scientific concepts (Van Uum et al., 2017). More recent innovations, including the use of digital simulations and virtual labs, have expanded instructional possibilities, enabling students to engage in complex scientific explorations even in resource-limited settings (Clark et al., 2009; Rutten et al., 2012).

Nonetheless, practical barriers continue to constrain the implementation of these pedagogical approaches. Resource limitations, such as a lack of laboratory facilities and instructional materials, are a common impediment, particularly in under-resourced schools (Rogan & Grayson, 2003; Roche et al., 2020). Furthermore, many teachers report feeling inadequately prepared to deliver inquiry-based science lessons, citing limited professional development opportunities and insufficient support structures (Kohler & Dietrich, 2021; Seneviratne et al., 2019). Curriculum rigidity also poses challenges, as national frameworks often prioritize content coverage over exploratory learning, leaving little room for pedagogical flexibility (Symaco & Daniel, 2018).

In response to these challenges, recent scholarship has explored the integration of emerging methodologies aimed at increasing student engagement. Storytelling, gamification, and place-based education are among the techniques being investigated for their potential to make science learning more relatable and enjoyable (Ibarra-Herrera et al., 2019; Kalogiannakis et al., 2021). At the same time, there is a growing emphasis on embedding environmental and sustainability education within the science curriculum to prepare students for global challenges (Logan, 2020).

The field has also benefited from bibliometric analyses that map research trends across various domains of science education. For example, Aktoprak and Hursen (2022) conducted a bibliometric review of critical thinking in primary education, while Jamali et al. (2023) examined global trends in STEM education. Kutlu-Abu et al. (2023) and Prahani et al. (2024) explored themes in scientific literacy and creativity, respectively. However, despite the availability of such studies, none have systematically analyzed the specific landscape of primary school science education. Bibliometric tools such as VOSviewer have proven effective in revealing knowledge structures, scholarly networks, and emerging themes (McAllister et al., 2022; Wang et al., 2023), suggesting their untapped potential in this domain.

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In sum, the literature demonstrates a robust theoretical and empirical foundation for primary science education, as well as a growing interest in innovative teaching practices. However, the lack of a comprehensive bibliometric synthesis represents a critical omission.

Research Aim and Research Questions

The overarching aim of this research was to conduct a bibliometric analysis to explore the structure and development of the academic field concerned with science education in primary schools, which has received increasing attention in prior studies. By identifying intellectual foundations and thematic clusters, the study aims to provide a meta-perspective that synthesizes current research trends and informs educational theory, instructional design, and policy planning.

To achieve this aim, the study addresses the following research questions:

I. What are the dominant thematic clusters and intellectual structures within the literature on primary school science education?
II. What emerging research areas, methodological approaches, and conceptual gaps can be identified through bibliometric mapping and co-word analysis?
III. How can these insights guide future inquiry, instructional innovation, and policy formulation in the context of early science learning?

Research Methodology

General Background

Bibliometrics is a quantitative research method that utilizes statistical and mathematical techniques to analyze scholarly literature, revealing intricate patterns, relationships, frequencies, and trends across scientific publications (Chandrakumar et al., 2024; Moral-Muñoz et al., 2020). Through the examination of citation counts, authorship networks, and keyword frequencies, bibliometric analysis provides a robust understanding of research productivity, impact, and the evolving landscape of academic inquiry (Bahroun et al., 2023). According to Chen et al. (2021), bibliometrics offers critical insights into the dynamics of scientific knowledge and academic communication and facilitates the identification of emerging trends and influential works, thereby guiding future research trajectories.

The bibliometric methodology adopted in this study followed the five-step approach outlined by Capobianco-Uriarte et al. (2019), comprising two primary stages: (1) identification of relevant scientific literature and (2) bibliometric analysis. Literature retrieval was guided by the transparent and replicable SPAR-4-SLR protocol (Paul et al., 2021), ensuring methodological rigor in the selection process. The bibliometric analysis was then conducted using VOSviewer 1.6.20, a widely recognized tool for mapping and visualizing bibliometric networks. Fauzi et al. (2024) noted that a comprehensive understanding of scholarly fields can be achieved by integrating bibliographic coupling and co-word analysis, which offer complementary insights into intellectual structures and thematic developments.

Bibliographic coupling analysis was employed to examine the extent to which two or more documents shared common references, thereby identifying intellectual proximity and thematic alignment within the field (Kleminski et al., 2022). When multiple publications cited the same sources, it suggested that they drew upon similar theoretical foundations or research traditions. This method was particularly useful for uncovering contemporary research frontiers, as it focused on how recent studies were grounded in shared bibliographic roots rather than historical citation patterns. In the context of science education in primary schools, bibliographic coupling analysis has facilitated the identification of current scholarly networks, active thematic clusters, and evolving research directions, offering insights into the structural cohesion and fragmentation within the field (Fauzi et al., 2024).

Co-word analysis, by contrast, examined the co-occurrence of keywords across documents, offering a lens into the conceptual and thematic landscape of a research area (Khasseh et al., 2021). By analyzing patterns of keyword association, researchers could detect emerging topics, dominant discourses, and evolving research priorities (Zhao et al., 2023). Applied to science education at the primary level, co-word analysis enabled a systematic exploration of both established and emergent areas of inquiry, serving as a strategic guide for future research (Dai et al., 2020). Thus, both bibliographic coupling and co-word analyses contributed to mapping the intellectual and thematic dimensions of the field over the period from 1997 to December 31, 2024.

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Sample

This bibliometric study analyzed a curated sample of 2,295 peer-reviewed journal articles related to science education at the primary level. The articles were selected from the Web of Science (WoS) Core Collection, including both the Science Citation Index Expanded (SCI-Expanded) and the Social Sciences Citation Index (SSCI). WoS was chosen for its high-quality, multidisciplinary coverage and consistent indexing standards, which are essential for reliable bibliometric analysis. The final number of 2,295 records reflects the application of carefully constructed Boolean search terms, relevance screening, and inclusion criteria focused on English-language journal articles to ensure global accessibility and scholarly impact. The search was conducted on May 5, 2025, and covered literature published from the inception of the database to the retrieval date.

Initial searches returned 1,044 records, which were then filtered for relevance and quality. To ensure methodological rigor, only English-language journal articles were included, consistent with bibliometric best practices aimed at capturing internationally accessible and high-impact research outputs (Singh et al., 2021; Pranckutė, 2021).

Instrument and Procedures

The primary instrument used for data retrieval was the Web of Science (WoS) platform, accessed on May 5, 2025. A structured Boolean keyword search was applied to the "Topic" field to ensure comprehensiveness. The keyword string used was: ("primary school" OR "elementary school" OR "grade school*" OR "junior school*" OR "primary grade*") AND ("scien* education" OR "scien* teach*" OR "scien* learn*" OR "scien* train*" OR "scien* curriculum*" OR "scien* pedagogy" OR "scien* stud*" OR "scien* literacy" OR "scien* instruction").

The search aimed to identify publications relevant to science education at the primary level. All retrieved metadata were exported in CSV and TXT formats and prepared for analysis. Data preprocessing included removal of duplicates, normalization of keywords, and elimination of irrelevant records using the Zupic and Čater (2015) bibliometric data-cleaning guidelines. Abstracts were screened manually to confirm alignment with the scope of the study.

Data Analysis

Data were analyzed using VOSviewer 1.6.20, a software tool widely used for visualizing bibliometric networks. The study employed bibliographic coupling analysis to identify influential publications and authors, and co-word analysis to explore conceptual patterns in keyword usage. These analyses enabled the generation of network maps and cluster visualizations representing dominant and emergent research themes.

The thematic clusters were interpreted through inductive reasoning, allowing patterns to emerge naturally from the data rather than imposing predefined categories. To increase the reliability of thematic interpretation, an inter-rater reliability check was performed. Each author independently reviewed the identified clusters, and discrepancies were discussed and resolved to reach consensus on the labeling and structure of the thematic categories.

This methodological approach provided a robust and replicable structure for understanding how the field of primary science education has evolved and what intellectual trajectories currently dominate. This bibliometric research provides sufficient methodological detail to ensure that future researchers can replicate the study or build upon its framework. While this study utilized quantitative bibliometric methods, it recognizes that future extensions may include qualitative content analysis of key clusters or mixed-method triangulation.

In line with the expectations of qualitative or mixed-method research, future studies may also consider exploring author collaboration networks, geographic distribution of contributions, and citation bursts to further enrich understanding of research dynamics in primary science education. The rigorous methodological design and cross-validation employed in this study ensure its credibility, replicability, and value to both academic and policy-making communities.

Research Results

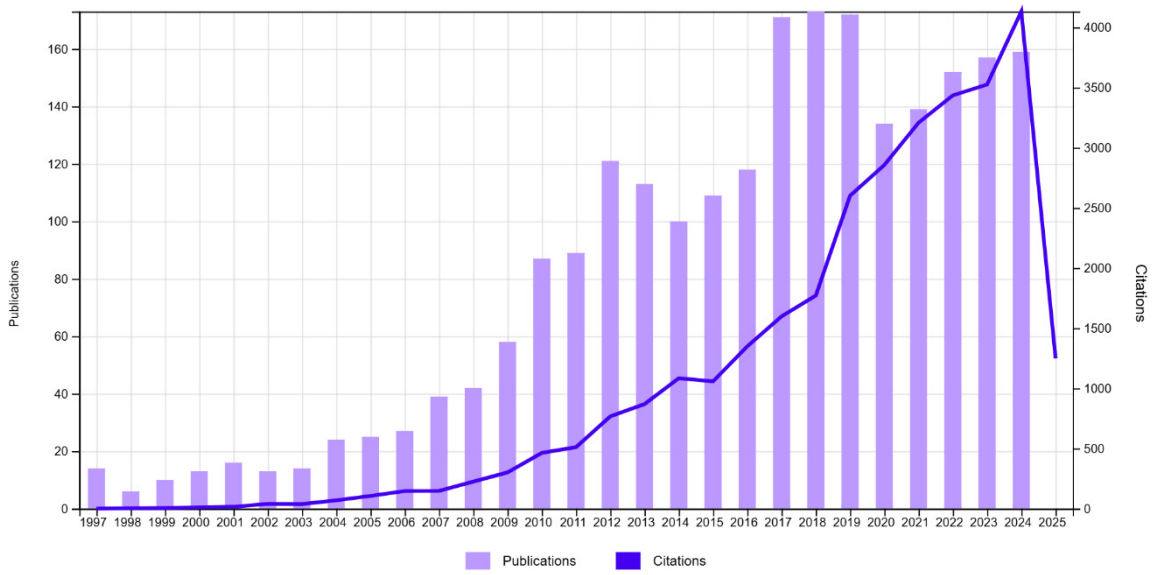
The WoS database returned a total of 31,582 citations for the selected 2,295 papers, excluding self-citations (29,805). The average citation count per paper was 13.76, with an H-index of 77. The presence of 2,295 papers demonstrated an increasing interest in research on science education in primary schools. Notably, the first publication in this field emerged in 1997, but significant contributions were not recognized until 2003. There was a marked

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exponential increase in publications from 2006 to 2019. However, from 2020 to 2023, publication growth remained relatively stagnant, likely due to the disruptions caused by the COVID-19 pandemic in many schools. These findings suggested a potential rise in future research on science education in primary schools. Figure 1 illustrates the publication trends and citation counts from 1997 to December 31, 2024.

Figure 1
Quantity of articles and citations from 1997 to Dec 31, 2024



Bibliographic Coupling Analysis

Bibliometric coupling analysis was conducted based on the cited references of the 2,295 publications examined. A minimum citation threshold of 89 was set for cited references. Of the 2,270 cited references, 57 met the threshold. Table 1 presents the top ten references, sorted by overall link strength. Specifically, the work of Zohar et al. (2013) received 39 TLS, Fauth et al. (2019) received 39 TLS, and Greene et al. (2018) received 32 TLS.

Table 1
The Highest Ten Publications Regarding Bibliometric Coupling Analysis and Overall Link Strength

No.	Publications	Citation	Overall link strength
1	Zohar, A., & Barzilai, S. (2013). A review of research on metacognition in science education: Current and future directions. Studies in Science Education, 49(2), 121-169.	207	39
2	Fauth, B., Decristan, J., Decker, A. T., Büttner, G., Hardy, I., Klieme, E., & Kunter, M. (2019). The effects of teacher competence on student outcomes in elementary science education: The mediating role of teaching quality. Teaching and Teacher Education, 86, Article 102882.	167	39
3	Greene, J. A., Cartiff, B. M., & Duke, R. F. (2018). A meta-analytic review of the relationship between epistemic cognition and academic achievement. Journal of Educational Psychology, 110(8), Article 1084.	89	32
4	Georghiades, P. (2004). From the general to the situated: Three decades of metacognition. International Journal of Science Education, 26(3), 365-383.	124	28

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No.	Publications	Citation	Overall link strength
5	Fauth, B., Decristan, J., Rieser, S., Klieme, E., & Büttner, G. (2014). Student ratings of teaching quality in primary school: Dimensions and prediction of student outcomes. Learning and Instruction, 29, 1-9	324	27
6	Zembal‐Saul, C. (2009). Learning to teach elementary school science as argument. Science Education, 93(4), 687-719.	129	26
7	Jaakkola, T., Nurmi, S., & Veermans, K. (2011). A comparison of students' conceptual understanding of electric circuits in simulation only and simulation‐laboratory contexts. Journal of Research in Science Teaching, 48(1), 71-93.	131	26
8	Georghiades, P. (2000). Beyond conceptual change learning in science education: Focusing on transfer, durability and metacognition. Educational Research, 42(2), 119-139.	106	24
9	Appleton, K. (2003). How do beginning primary school teachers cope with science? Toward an understanding of science teaching practice. Research in Science Education, 33(1), 1-25.	182	23
10	Manz, E. (2015). Resistance and the development of scientific practice: Designing the mangle into science instruction. Cognition and Instruction, 33(2), 89-124.	95	23

Source: Author's interpretation from VOSviewer.

Figure 2 presents the network model derived from the analyzed publications. The visualization reveals five distinct clusters, each representing a group of documents with thematic similarities. Publications sharing common features are grouped together, and each cluster is color-coded for visual distinction (Wu et al., 2022). The classification and detailed explanation of each cluster are provided below:

Cluster 1: Augmented Reality, Virtual Reality, and ICT Integration in Primary Science Education

Cluster 1 comprises 21 publications focused on the integration of advanced digital technologies, particularly augmented reality (AR), virtual reality (VR), and various forms of information and communication technology (ICT), into primary science education. The literature in this cluster collectively underscored the transformative potential of immersive and interactive digital tools in enhancing conceptual understanding, student motivation, and classroom engagement. Studies such as those by Chang and Hwang (2018) and Lai et al. (2019) demonstrated that AR-based instructional approaches, designed in accordance with cognitive load theory, significantly improved learning outcomes by increasing student attention, comprehension, and performance in science-related tasks. Meta-analytic findings by Chang et al. (2022) further validated the consistent positive impact of AR on science learning over the past decade. Despite these advantages, contextual challenges persisted. For instance, Alalwan et al. (2020) highlighted the technological, infrastructural, and pedagogical barriers faced by schools in developing countries. Moreover, the effective implementation of digital tools was contingent on teachers' technological pedagogical competencies. Research by Donnelly et al. (2011) and Jang and Tsai (2012) emphasized the critical role of Technological Pedagogical Content Knowledge (TPACK) in integrating tools such as interactive whiteboards into science instruction. Additionally, Su and Cheng (2015) explored the benefits of mobile gamification, revealing its potential to enhance both student achievement and intrinsic motivation.

Cluster 2: Equity, Engagement, and Teacher Competence in Primary Science Achievement

This cluster, comprising 13 publications, addressed the interrelated themes of educational equity, student engagement, and teacher competence in the context of science achievement. The literature emphasized that disparities in science outcomes often emerged during early schooling and were shaped by a range of modifiable contextual factors. For example, Morgan et al. (2016) reported that socioeconomic background, home environment, and access to educational resources played significant roles in shaping early science achievement. These findings underscored the importance of timely interventions. Teacher quality was a particularly salient theme in this cluster. Fauth et al. (2019) identified instructional quality as a key mediating factor between teacher competence and

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student learning outcomes, highlighting the need for targeted professional development. Manz (2015) advocated for the inclusion of "productive struggle" in inquiry-based science instruction, suggesting that engagement with complex problems enhanced epistemic agency and deeper learning. Furthermore, research by Rotgans and Schmidt (2017) and Schmidt et al. (2018) explored the construct of situational interest, demonstrating that context-specific instructional strategies could foster sustained student motivation.

Cluster 3: Cognitive and Metacognitive Supports in Conceptual Understanding of Science

Cluster 3 includes eight publications that examined the cognitive and metacognitive dimensions of science learning in primary education. A central theme across these studies was the importance of providing cognitive scaffolds and opportunities for metacognitive reflection to facilitate conceptual change. For instance, English and King (2015) illustrated the benefits of engineering design-based learning in fostering meaningful understanding of STEM concepts among fourth-grade students. Similarly, Jaakkola and Nurmi (2008) and Jaakkola et al. (2011) compared various instructional modalities, including simulations, laboratory experiments, and hybrid approaches, and concluded that multimodal strategies enhanced learners' conceptual clarity. In terms of metacognitive processes, Georghiades (2004) and Zohar and Barzilai (2013) emphasized the significance of fostering self-regulation, reflection, and awareness of one's own learning strategies in science instruction. These elements were crucial for promoting deep understanding rather than surface-level memorization. Social and linguistic variables also emerged in this cluster. For example, Crowley et al. (2001) highlighted gender differences in scientific explanations provided by parents, suggesting that early socialization may have contributed to disparities in science learning. Diakidoy et al. (2003) investigated how the structure of science texts influenced students' conceptual change, underscoring the role of discourse in cognitive development.

Cluster 4: Dialogic Teaching, Integration, and Teacher Beliefs in Science Literacy

This cluster, which includes six publications, focuses on dialogic teaching approaches, interdisciplinary integration, and the role of teacher beliefs in developing science literacy. Dialogic pedagogy, characterized by open-ended questioning, argumentation, and collaborative reasoning, was shown to enhance students' scientific thinking and communication skills. Howe et al. (2007) and Mercer et al. (2009) provided compelling evidence that group-based and dialogic teaching strategies created opportunities for knowledge co-construction and critical discussion in science classrooms. Another significant theme in this cluster was the integration of science and literacy instruction. Studies by Cervetti et al. (2012) and Pappas (2006) demonstrated that combining science content with literacy activities not only improved reading comprehension but also enhanced content knowledge, thereby fostering dual-domain competence. The importance of teacher beliefs was also emphasized. Palmer (2006) and Murphy et al. (2007) examined teacher self-efficacy and confidence, revealing that these factors significantly influenced instructional choices and student learning outcomes.

Cluster 5: Artificial Intelligence, Computer Science, and Computational Thinking in Early and Primary Education

Cluster 5, consisting of seven publications, explores the integration of artificial intelligence (AI), computer science (CS), and computational thinking (CT) into early and primary science education. The literature reflected a growing consensus that computational competencies should be introduced from an early age to prepare students for participation in increasingly digital societies. Kandlhofer et al. (2016) advocated for age-appropriate robotics and programming activities, demonstrating their feasibility and value even at the preschool level. Curricular and pedagogical frameworks were also examined. Webb et al. (2017) analyzed the rationale, scope, and implementation strategies for embedding CS education into K–12 curricula, while Buitrago Flórez et al. (2017) and Chen et al. (2017) presented empirical evidence supporting the positive effects of programming instruction on students' problem-solving and logical reasoning skills. Repenning et al. (2015) introduced the concept of scalable game design as a pedagogical model that enables learners to progressively develop computational proficiency. Greene et al. (2018) extended this discussion by linking students' epistemic beliefs to their engagement and success in STEM subjects, including computer science.

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Figure 2
Bibliometric coupling analysis of science education in primary schools

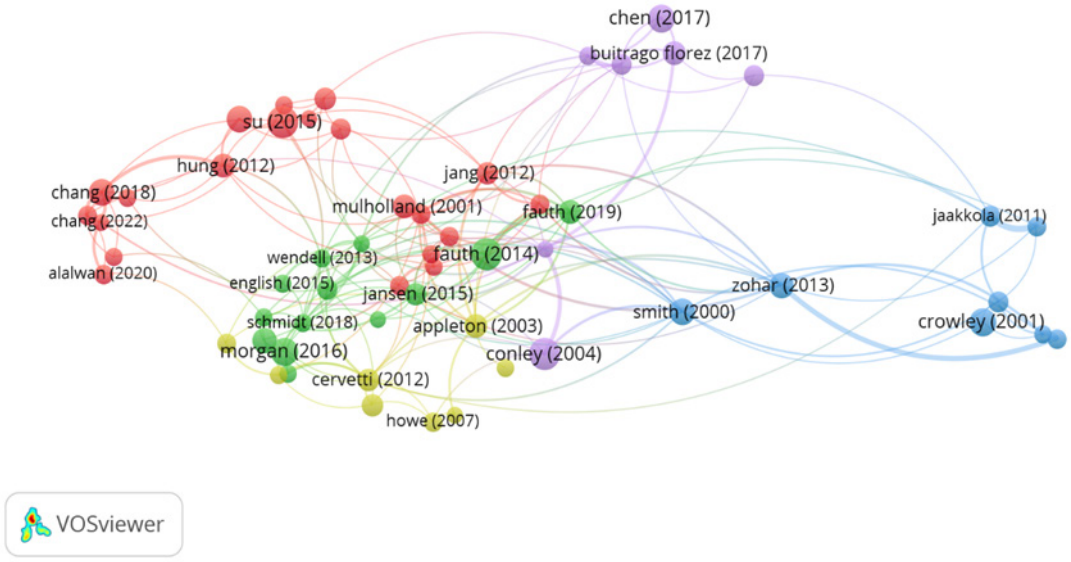


Table 2 provides a summary of the bibliometric coupling analysis, including clustering amount and color, tags, number of papers, and representative papers.

Table 2
Bibliometric Coupling Clusters Related to Science Education in Primary Schools

Cluster	Cluster tag	Number of publications	Representative publications
1	Augmented Reality (AR), Virtual Reality (VR), and ICT Integration in Primary Science Education	21	Chang & Hwang (2018), Chang et al. (2022), Donnelly et al. (2011), Lai et al. (2019), Alalwan et al. (2020), Jang & Tsai (2012), Su & Cheng (2015)
2	Equity, Engagement, and Teacher Competence in Primary Science Achievement	13	Morgan et al. (2016), Manz (2015), Fauth et al. (2019), Rotgans and Schmidt (2017), Schmidt et al. (2018)
3	Cognitive and Metacognitive Supports in Conceptual Understanding of Science	8	English and King (2015), Crowley et al. (2001), Jaakkola and Nurmi (2008), Diakidoy et al. (2003), Georghiades (2004), Jaakkola et al. (2011), Zohar and Barzilai (2013)
4	Dialogic Teaching, Integration, and Teacher Beliefs in Science Literacy	8	Mercer et al. (2009), Howe et al. (2007), Cervetti et al. (2012), Palmer (2006), Pappas (2006), Murphy et al. (2007)
5	Artificial Intelligence, Computer Science, and Computational Thinking in Early and Primary Education	7	Kandlhofer et al. (2016), Greene et al. (2018), Webb et al. (2017), Chen et al. (2017), Buitrago Flórez et al. (2017), Repenning et al. (2015)

Source: Author's interpretation from VOSviewer.

Co-occurrence of Keyword

In the dataset, a threshold of at least 32 occurrences per keyword was established, identifying 60 unique keywords of the 5928 keywords. The keyword "education" appeared most frequently, with 340 occurrences, next to "science education" with 362 occurrences and "students" with 234 occurrences. Following the co-word analysis, the highest 15 keywords are listed in Table 3.

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Table 3
The Highest 15 Keywords in Co-word Analysis

No.	Keyword	Occurrences	Overall link strength
1	Education	340	973
2	Science Education	362	838
3	Students	234	739
4	Science	272	727
5	Knowledge	226	725
6	Inquiry	153	531
7	Achievement	121	419
8	Beliefs	102	399
9	Primary School	168	368
10	Attitudes	100	344
11	Teachers	110	343
12	Elementary School	127	328
13	Instruction	89	314
14	Self-efficacy	91	314
15	Motivation	81	296

Source: Author's interpretation from VOSviewer.

The second objective of this study aimed to uncover potential research themes in primary school science education by analyzing keyword co-occurrence. The results identified four thematic clusters, each of which reflects a distinct trajectory in the evolution of science education scholarship. These clusters offer insight into how current research interests are coalescing around issues of discourse, pedagogy, student learning, and technological integration.

Cluster 1: Dialogic Argumentation, Discourse, and Scientific Literacy

The first cluster emphasizes the increasing relevance of argumentation, discourse-driven inquiry, and scientific literacy in primary science education. It reflects a pedagogical shift from procedural knowledge acquisition toward practices that develop students' reasoning, language, and critical thinking skills. Recent literature underscores the effectiveness of creating authentic, dialogic classroom environments in which students actively construct scientific meaning through discussion and collaborative exploration (Mansour, 2024). These environments not only promote scientific literacy but also enhance students' language development and conceptual understanding (Ramulumo, 2024; Syofyan et al., 2025). Furthermore, empirical and meta-analytic studies show that embedding augmented reality tools and leveraging students' intrinsic interests within inquiry-based instruction lead to greater engagement and more sophisticated reasoning (Li et al., 2025). Teacher adaptability and responsiveness are also critical, with findings indicating that educators must adopt dynamic strategies that encourage meaningful scientific discourse and inquiry (Hardy et al., 2022; Ajani, 2024). This cluster points to future research directions, including longitudinal studies on the development of argumentation skills, investigations into discourse practices in multilingual classrooms, and the design of automated tools to assess dialogic interaction and its relationship to conceptual growth.

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Cluster 2: Teacher Beliefs, Pedagogical Knowledge, and Professional Development

The second cluster centers on the importance of teacher-related variables, including beliefs, self-efficacy, and pedagogical content knowledge, influencing student outcomes in science and mathematics. The literature affirms that effective teaching is closely linked to instructors' conceptions of science, their confidence in implementing reform-based instruction, and their engagement in sustained professional growth (Tsaliki et al., 2022). Reform-oriented frameworks that prioritize reflective practice and collaborative learning communities have shown promise in strengthening instructional quality (Tinkler et al., 2024; Yokota, 2024). Ali et al. (2023) argue that teachers must develop a nuanced understanding of both content and pedagogy to effectively navigate curricular reforms and implement meaningful change. Empirical findings further suggest that professional development aligned with research-based strategies, particularly those that promote teacher agency, critical reflection, and contextually responsive decision-making, enhances both teacher preparedness and student engagement (Lee, 2024). Future research should investigate the longitudinal effects of teacher learning trajectories, the mechanisms through which belief systems shape instructional practice, and the development of equity-focused professional development models that foster resilience and innovation (Gomero, 2024; Ivey, 2024).

Cluster 3: Achievement, Engagement, and Conceptual Change

The third cluster reveals a strong interest in promoting student achievement and conceptual change through integrated motivational and instructional strategies. Recent studies underscore the need to design learning experiences that acknowledge students' pre-existing beliefs and misconceptions while simultaneously fostering sustained engagement and deeper conceptual understanding (Abu et al., 2023; Alajmi, 2025). Research in this cluster suggests that incorporating technological tools, such as augmented reality, can serve as powerful scaffolds for enhancing motivation and cognitive clarity, particularly in complex scientific domains like physics and systems thinking (Ateş, 2025). Instructional interventions that blend emotional support, tailored feedback, and formative assessment are shown to significantly improve learning outcomes (Bommanaboina & Bommanaboina, 2024; Prastikawati et al., 2024). This cluster signals a need for future research on the development of personalized, adaptive instructional environments that integrate real-time feedback, affective sensing, and conceptual scaffolding. Additionally, further exploration is warranted into the long-term impact of these strategies on students' scientific identity formation and the transferability of learning across academic subjects (Ayangbola, 2024; Archer & Mendick, 2025).

Cluster 4: Computational Thinking and Technology Integration in STEM Education

The fourth cluster reflects growing scholarly and practical interest in integrating computational thinking (CT), artificial intelligence (AI), and computer science (CS) into primary science education. Between 2022 and 2024, this area has gained momentum as educators and researchers increasingly recognize the importance of cultivating digital fluency and problem-solving skills from an early age (Mee et al., 2025). The incorporation of CT and CS into STEM curricula has been associated with improvements in logical reasoning, algorithmic thinking, and student engagement, particularly when lessons are designed to promote inclusivity and positive learner perceptions (Ali & Elkot, 2025). Gender equity and thoughtful curriculum design must also be addressed to ensure broad and sustained participation in STEM fields (Daraz et al., 2024). Moreover, teacher and student perceptions of technology adoption are shown to influence both motivation and implementation fidelity (Richardson, 2024). This cluster highlights the need for research into curriculum frameworks that define age-appropriate progressions in CT and evaluate cost-effective, scalable models, such as unplugged or low-tech coding interventions, that can be implemented in resource-constrained settings.

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Figure 3
Co-word analysis of science education in primary schools.

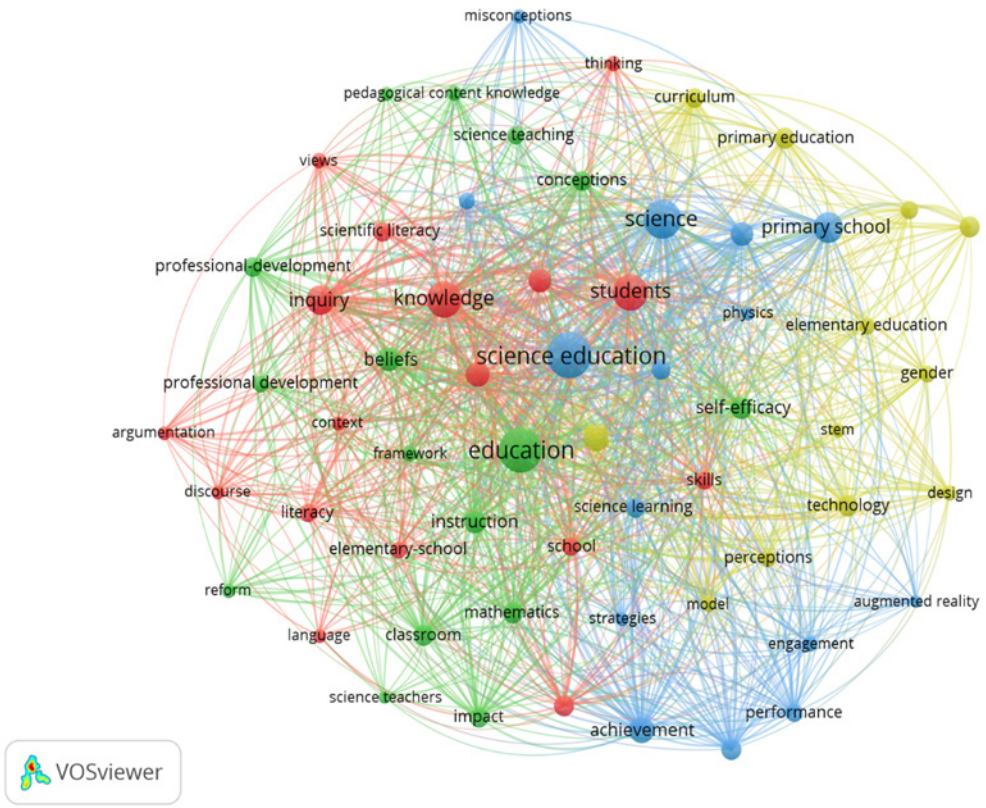


Table 4 summarizes the co-word analysis of science education in primary schools, including four clustering amounts and colors, tags, total number of terms, and representative terms.

Table 4
Co-word Analysis on Science Education in Primary Schools

Cluster	Cluster tag	Number of terms	Representative terms
1	Dialogic Argumentation, Discourse, and Scientific Literacy	17	Argumentation, children, context, discourse, elementary-school, inquiry, knowledge, language, literacy, school, science-education, scientific literacy, skills, students, teachers, thinking, views
2	Teacher Beliefs, Pedagogical Knowledge, and Professional Development	16	Beliefs, classroom, conceptions, education, education, framework, impact, instruction, mathematics, pedagogical content knowledge, professional-development, reform, science teachers, science teaching, self-efficacy, teacher education
3	Achievement, Engagement, and Conceptual Change	15	Achievement, attitudes, augmented reality, conceptual change, elementary, engagement, misconceptions, motivation, performance, physics, primary school, science, science education, science learning, strategies
4	Computational Thinking and Technology Integration in STEM Education	12	Computational thinking, computer science education, curriculum, design, elementary education, elementary school, gender, model, perceptions, primary education, stem, technology

Source: Author's interpretation from VOSviewer.

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Discussion

The findings of this bibliometric analysis offered more than a retrospective account of existing scholarship; they provide a strategic foundation for reimagining primary science education as an inclusive, inquiry-driven, and future-oriented discipline. Situated within a global context where early science learning is increasingly tied to national innovation capacity and civic scientific literacy (Jia et al., 2024), this study highlights how research in the field is undergoing a paradigmatic shift, from content transmission to epistemic participation, and from procedural tasks to dialogic, technology-enabled inquiry. These shifts carry weighty implications for theory, pedagogy, and policy.

At the theoretical level, this study reveals the urgent need to reconceptualize science learning in the primary years not as a linear process of concept acquisition but as a socio-cognitive engagement with the practices of science. The clustering around keywords such as "argumentation," "discourse," and "scientific literacy" reflects a growing recognition that primary science classrooms are not merely sites of knowledge delivery but incubators for epistemic agency. This calls for new theoretical models that bridge sociocultural learning theories with conceptual change framework models that attend to the formative role of dialogue, identity, and reasoning in how young learners make sense of scientific phenomena (Mercer et al., 2009; Zohar & Barzilai, 2013). Equally important is the incorporation of metacognition and affect into these frameworks, as evidenced by studies emphasizing the role of motivation, curiosity, and self-regulated learning in conceptual development (Jaakkola et al., 2011; Fauth et al., 2019).

The analysis also foregrounds teacher cognition and pedagogical knowledge as critical nodes in the science education ecosystem. The intellectual convergence around teacher beliefs, professional development, and instructional quality suggests that pedagogical reform is unlikely to succeed without first addressing the epistemological stances of educators themselves. This underscores a need for models such as Critical-TPACK, an expansion of Technological Pedagogical Content Knowledge (Jang & Tsai, 2012), which integrates an equity lens and situates teachers as reflective practitioners navigating complex socio-technical environments. Rather than treating professional learning as a technical training exercise, future research and interventions should conceptualize it as a form of identity work, where teachers critically examine their assumptions, positionality, and capacity to enact transformative science pedagogies in under-resourced and diverse settings (Manz, 2015; Murphy et al., 2007).

The rise of digital tools in primary science instruction, especially augmented and virtual reality, marks a pivotal turning point for instructional design. These technologies are not neutral enhancers of learning; they reconfigure what and how students learn, making it essential to understand their pedagogical logic and cognitive demands. This study identifies a growing body of work that demonstrates how AR-based learning environments enhance motivation, conceptual clarity, and engagement, particularly when grounded in cognitive load theory (Lai et al., 2019). Yet the findings also suggest that the efficacy of these tools is conditionally dependent on context, infrastructure, and, most critically, teacher competence. Thus, the challenge lies in expanding access to educational technologies and cultivating pedagogical fluency that ensures their integration aligns with inquiry-based, student-centered principles.

Another pressing implication emerges from the intersection of computational thinking and science education. The thematic cluster on CT, AI, and CS integration indicates that science education in primary schools is beginning to engage with the epistemologies of the digital age. This redefines what it means to be scientifically literate, encompassing not only an understanding of natural phenomena but also how data, algorithms, and simulations shape human understanding and action (Webb et al., 2017; Kandlhofer et al., 2016). Embedding computational practices within science curricula from the early years through unplugged coding, robotics, or scalable game design not only enhances logical reasoning and problem-solving but also opens new pathways for interdisciplinary learning (Buitrago Flórez et al., 2017; Repenning et al., 2015). However, without careful attention to gender, culture, and access, these innovations risk reinforcing existing inequities. The field must, therefore, move toward designing culturally responsive, inclusive CT interventions that resonate with learners' lived experiences and aspirations (Greene et al., 2018).

To address these converging developments and provide a future-oriented roadmap, we propose the DIG-EDU-QUEST framework: Dialogic–Inclusive–Generative Education for Quality, Equity, Science, and Technology. This framework is grounded in the findings of the present bibliometric analysis. It is designed to unify three critical drivers of primary science education reform: Pedagogical Practices, Technological Affordances, and Sociocultural Equity, all anchored around a core process of Culturally Responsive Inquiry (CRI). Rather than treating these components as separate, DIG-EDU-QUEST theorizes their dynamic interaction as essential to cultivating cognitive, affective, equity, and systemic outcomes. The framework also proposes several testable hypotheses to guide future mixed-method research and cross-national experimentation. The DIG-EDU-QUEST framework is summarized in Table 5.

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Table 5
DIG-EDU-QUEST Framework for Transforming Primary Science Education

Core Element	Components	Key Propositions	Expected Outcomes
Culturally Responsive Inquiry (CRI)	Dialogic exploration, epistemic agency, contextualized tasks	Students construct meaning through culturally relevant inquiry cycles	Deeper conceptual learning, scientific literacy, identity formation
Pedagogical Practices	Dialogic teaching, cognitive/metacognitive scaffolds, teacher identity work (Critical-TPACK)	Quality instruction depends on teachers' beliefs, self-efficacy, and inquiry fluency	Increased motivation, self-regulation, and instructional quality
Technological Affordances	AR/VR tools, computational thinking, adaptive analytics	Technology enhances learning only when meaningfully integrated into CRI	Improved engagement, cognitive clarity, and personalized feedback
Sociocultural Equity	Digital access, inclusive curriculum design, policy alignment	Equity moderates pedagogical and technological impact	Reduced achievement gaps, increased participation across demographics

At the systems level, this framework underscores the need for robust policy support. Bibliometric evidence suggests the need to recalibrate science education standards to prioritize discourse, inquiry, and computational reasoning alongside traditional content knowledge. Policy frameworks must support schools not only with digital infrastructure but also with sustained investments in teacher capacity, adaptive curricula, and embedded formative assessment tools aligned with inquiry-based goals (National Research Council, 1996; Zembal-Saul, 2009). Importantly, equity must not be an afterthought. Monitoring systems that track engagement, performance, and participation across diverse student demographics are crucial for identifying and addressing disparities early (Morgan et al., 2016; Rotgans & Schmidt, 2017).

Conclusions and Implications

This bibliometric study addresses a critical void in the literature by offering the first comprehensive mapping of primary school science education research using bibliographic coupling and co-word analysis. By examining 2,295 publications indexed in the WoS, the study elucidates the intellectual structure, thematic trends, and evolving priorities that shape this field. The five identified clusters, ranging from technology integration and teacher competence to metacognitive support, dialogic literacy, and computational thinking, demonstrate that science education at the primary level is undergoing a profound paradigmatic shift toward inquiry-based, digitally supported, and equity-oriented pedagogies.

The significance of this study lies in its capacity to make sense of an increasingly complex research landscape and to provide an evidence-based foundation for theoretical, pedagogical, and policy innovations. Science education in the early years is not merely a national imperative but a global one: it cultivates future generations of critical thinkers, problem solvers, and informed citizens who will navigate and shape the science-driven challenges of the 21st century, from climate change to technological disruption. In a world marked by rapid scientific advancement and deepening global inequities, the ability to build scientific literacy from the ground up is not optional; it is essential.

The conclusions drawn from this analysis have broad international relevance. First, they signal that despite variations in national curricula and infrastructure, there is a global convergence around the need for dialogic, student-centered approaches that promote epistemic agency. Second, the prominence of themes such as digital learning environments, equity in science achievement, and early exposure to computational thinking reflects cross-national concerns about preparing all children, not just those in high-resource settings, for participation in science and technology futures. Third, this study provides a strategic roadmap for countries aiming to reform their science education systems by identifying best practices, research gaps, and underexplored topics such as teacher identity in reform contexts and cultural responsiveness in digital pedagogies.

In response to these trends, this study proposes the DIG-EDU-QUEST framework as a forward-looking model for guiding theory, practice, and policy. The DIG-EDU-QUEST framework offers a testable, integrative approach that not only synthesizes existing evidence but also challenges traditional, transmission-based assumptions in

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primary science education. It encourages the design of research programs and instructional interventions that are inquiry-rich, culturally grounded, and digitally enabled, with a particular focus on scalability in low- and middle-income contexts.

Practically, the findings suggest the design of scalable, inclusive interventions, particularly in low- and middle-income countries, where issues of access, teacher training, and curriculum flexibility are particularly pressing. The bibliometric trends suggest that investment in teacher professional development, technology integration guided by pedagogical principles, and curriculum innovation anchored in inquiry and equity can collectively elevate science learning outcomes globally.

Moving forward, future studies should address the current study's limitations by integrating qualitative methodologies that explore how key pedagogical themes, such as cultural responsiveness and inquiry-based teaching, are enacted in diverse classroom settings. In addition, expanding data sources to include non-English publications and regional databases beyond WoS would help mitigate language and indexing bias, offering a more culturally nuanced and globally representative understanding of what drives effective and equitable science education at the primary level.

This study not only maps where the field has been but also outlines where it needs to go. By doing so, it equips researchers, educators, and policymakers with the empirical clarity and strategic vision needed to transform primary science education into a globally relevant and socially responsive domain of learning.

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Declaration of Interest

The authors declare no competing interest.

References

Ajani, O. A. (2024). Enhancing pre-service teacher education: Crafting a technology-responsive curriculum for modern classrooms and adaptive learners. *Research in Educational Policy and Management, 6*(2), 209–229. https://doi.org/10.46303/repam.2024.32

Aktoprak, A., & Hürsen, C. (2022). A bibliometric and content analysis of critical thinking in primary education. *Thinking Skills and Creativity, 44*, Article 101029. https://doi.org/10.1016/j.tsc.2022.101029

Alajmi, T. D. (2025). *Inside the mind of pre-service science teachers: Examining the impact of prior experiences and the influence of science education programs on pedagogical beliefs* (Doctoral dissertation, Oregon State University).

Alalwan, N., Cheng, L., Al-Samarraie, H., Yousef, R., Alzahrani, A. I., & Sarsam, S. M. (2020). Challenges and prospects of virtual reality and augmented reality utilization among primary school teachers: A developing country perspective. *Studies in Educational Evaluation*, *66*, Article 100876. https://doi.org/10.1016/j.stueduc.2020.100876

Ali, R., & Elkot, M. A. (2025). Empowering educators integrating computational thinking, AI, and STEM: Fostering innovation through technology and education. In M. A. Elkot & R. Ali (Eds.), In *empowering STEM educators with digital tools* (pp. 29–58). IGI Global Scientific Publishing.

Ali, Z., Ullah, N., Ahmad, N., Yaqoob, N., & Saba, F. (2023). Teachers' perceptions of curriculum change and the need of professional development for effective teaching practices. *Multicultural Education*, *9*(1), 83–90.

Appleton, K. (2003). How do beginning primary school teachers cope with science? Toward an understanding of science teaching practice. *Research in science education*, *33*(1), 1–25. https://doi.org/10.1023/A:1023666618800

Archer, L., & Mendick, H. (2025). Becoming exceptional: The role of capital in the development and mediation of mathematics identity and degree trajectories. *Educational Studies in Mathematics, 118*(1), 119–137.

Ateş, H. (2025). Integrating augmented reality into intelligent tutoring systems to enhance science education outcomes. *Education and Information Technologies, 30*(4), 4435–4470.

Ayangbola, O. T. (2024). *Unraveling the complexities of science identity development among first-generation college students in learning assistant-supported introductory science classes* (Doctoral dissertation, Middle Tennessee State University).

Bahroun, Z., Anane, C., Ahmed, V., & Zacca, A. (2023). Transforming education: A comprehensive review of generative artificial intelligence in educational settings through bibliometric and content analysis. *Sustainability, 15*(17), *Article* 12983. https://doi.org/10.3390/su151712983

https://doi.org/10.33225/jbse/25.24.756

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Bommanaboina, L. D., & Bommanaboina, R. D. (2024). Enhancing ESL preservice teachers' formative assessment skills: Developing reflective analytic rubrics for language assessment tasks. *The International Journal of Humanities Education, 23*(1), 69–102.

Buitrago Flórez, F., Casallas, R., Hernández, M., Reyes, A., Restrepo, S., & Danies, G. (2017). Changing a generation's way of thinking: Teaching computational thinking through programming. *Review of Educational Research, 87*(4), 834–860. https://doi.org/10.3102/0034654317710096

Capobianco-Uriarte, M. de l. M., Casado-Belmonte, M. de P., Marín-Carrillo, G. M., & Terán-Yépez, E. (2019). A bibliometric analysis of international competitiveness (1983–2017). *Sustainability, 11*(7), *Article* 1877. https://doi.org/10.3390/su11071877

Cervetti, G. N., Barber, J., Dorph, R., Pearson, P. D., & Goldschmidt, P. G. (2012). The impact of an integrated approach to science and literacy in elementary school classrooms. *Journal of Research in Science Teaching, 49*(5), 631–658. https://doi.org/10.1002/tea.21015

Chandrakumar, D., Arumugam, V., & Vasudevan, A. (2024). Exploring presenteeism trends: A comprehensive bibliometric and content analysis. *Frontiers in Psychology, 15*, *Article* 1352602. https://doi.org/10.3389/fpsyg.2024.1352602

Chang, H. Y., Binali, T., Liang, J. C., Chiou, G. L., Cheng, K. H., Lee, S. W. Y., & Tsai, C. C. (2022). Ten years of augmented reality in education: A meta-analysis of (quasi-) experimental studies to investigate the impact. *Computers & Education, 191*, Article 104641. https://doi.org/10.1016/j.compedu.2022.104641

Chang, S. C., & Hwang, G. J. (2018). Impacts of an augmented reality-based flipped learning guiding approach on students' scientific project performance and perceptions. *Computers & Education, 125*, 226–239. https://doi.org/10.1016/j.compedu.2018.06.007

Chen, G., Shen, J., Barth-Cohen, L., Jiang, S., Huang, X., & Eltoukhy, M. (2017). Assessing elementary students' computational thinking in everyday reasoning and robotics programming. *Computers & Education, 109*, 162–175. https://doi.org/10.1016/j.compedu.2017.03.001

Chen, X., Zou, D., Xie, H., & Wang, F. L. (2021). Past, present, and future of smart learning: A topic-based bibliometric analysis. *International Journal of Educational Technology in Higher Education, 18*, *Article* 2. https://doi.org/10.1186/s41239-020-00247-2

Clark, D., Nelson, B., Sengupta, P., & D'Angelo, C. (2009). Rethinking science learning through digital games and simulations: Genres, examples, and evidence. In National Academy of Sciences (Ed.), *Learning science: Computer games, simulations, and education workshop*. National Academy Press.

Crowley, K., Callanan, M. A., Tenenbaum, H. R., & Allen, E. (2001). Parents explain more often to boys than to girls during shared scientific thinking. *Psychological Science, 12*(3), 258–261. https://doi.org/10.1111/1467-9280.00347

Dai, S., Duan, X., & Zhang, W. (2020). Knowledge map of environmental crisis management based on keyword network and co-word analysis (2005–2018). *Journal of Cleaner Production, 262*, Article 121168. https://doi.org/10.1016/j.jclepro.2020.121168

Daraz, U., Khan, Y., Ashraf, M. A., & Tsegay, S. M. (2024). Bridging the gap: Progressive teaching strategies for gender equity in STEM education. *IntechOpen*. https://doi.org/10.5772/intechopen.114860

Devi, K. S. (2019). Constructivist approach to learning based on the concepts of Jean Piaget and Lev Vygotsky. *The NCERT, 44*(4), 5–19.

Diakidoy, I. A. N., Kendeou, P., & Ioannides, C. (2003). Reading about energy: The effects of text structure in science learning and conceptual change. *Contemporary Educational Psychology, 28*(3), 335–356. https://doi.org/10.1016/S0361-476X(02)00039-5

Donnelly, D., McGarr, O., & O'Reilly, J. (2011). A framework for teachers' integration of ICT into their classroom practice. *Computers & Education, 57*(2), 1469–1483. https://doi.org/10.1016/j.compedu.2011.02.014

English, L. D., & King, D. T. (2015). STEM learning through engineering design: Fourth-grade students' investigations in aerospace. *International Journal of STEM Education, 2*(1), Article 14. https://doi.org/10.1186/s40594-015-0027-7

Fauth, B., Decristan, J., Decker, A. T., Büttner, G., Hardy, I., Klieme, E., & Kunter, M. (2019). The effects of teacher competence on student outcomes in elementary science education: The mediating role of teaching quality. *Teaching and Teacher Education, 86*, Article 102882. https://doi.org/10.1016/j.tate.2019.102882

Fauth, B., Decristan, J., Rieser, S., Klieme, E., & Büttner, G. (2014). Student ratings of teaching quality in primary school: Dimensions and prediction of student outcomes. *Learning and Instruction, 29*, 1–9. https://doi.org/10.1016/j.learninstruc.2013.07.001

Fauzi, M. A., Mohamad, F., & Abdul Wahab, N. (2024). Knowledge sharing via social media in higher education: a bibliometric analysis. *Journal of Applied Research in Higher Education*, *16*(5), 1420–1437.

Georghiades, P. (2000). Beyond conceptual change learning in science education: Focusing on transfer, durability and metacognition. *Educational Research, 42*(2), 119–139. https://doi.org/10.1080/001318800363773

Georghiades, P. (2004). From the general to the situated: Three decades of metacognition. *International Journal of Science Education, 26*(3), 365–383. https://doi.org/10.1080/0950069032000119401

Gomero, I. (2024). *Lessons learned and supports needed by educational leaders after participation in equity-focused professional learning: A qualitative case study* (Doctoral dissertation, Central Connecticut State University).

Greene, J. A., Cartiff, B. M., & Duke, R. F. (2018). A meta-analytic review of the relationship between epistemic cognition and academic achievement. *Journal of Educational Psychology, 110*(8), *Article* 1084. https://doi.org/10.1037/edu0000263

Hardy, I., Meschede, N., & Mannel, S. (2022). Measuring adaptive teaching in classroom discourse: Effects on student learning in elementary science education. *Frontiers in Education, 7*, Article 1041316. https://doi.org/10.3389/feduc.2022.1041316

Hein, G. E. (1991). Constructivist learning theory. *Institute for Inquiry*. http://www.exploratorium.edu/ifi/resources/constructivistlearning.html

Hernandez-de-Menendez, M., Escobar Díaz, C., & Morales-Menendez, R. (2020). Technologies for the future of learning: State of the art. *International Journal on Interactive Design and Manufacturing, 14*(2), 683–695. https://doi.org/10.1007/s12008-020-00662-8

Howe, C., Tolmie, A., Thurston, A., Topping, K., Christie, D., Livingston, K., ... & Donaldson, C. (2007). Group work in elementary science: Towards organisational principles for supporting pupil learning. *Learning and Instruction, 17*(5), 549–563. https://doi.org/10.1016/j.learninstruc.2007.09.004

https://doi.org/10.33225/jbse/25.24.756

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Ibarra-Herrera, C. C., Carrizosa, A., Yunes-Rojas, J. A., & Mata-Gómez, M. A. (2019). Design of an app based on gamification and storytelling as a tool for biology courses. *International Journal on Interactive Design and Manufacturing, 13*, 1271–1282. https://doi.org/10.1007/s12008-019-00560-2

Ivey, A. S. (2024). *Examining Black educators' equity leadership and implications for critical professional development amidst the COVID-19 pandemic* (Doctoral dissertation, University of California, Davis).

Jaakkola, T., & Nurmi, S. (2008). Fostering elementary school students' understanding of simple electricity by combining simulation and laboratory activities. *Journal of Computer Assisted Learning, 24*(4), 271–283. https://doi.org/10.1111/j.1365-2729.2007.00259.x

Jaakkola, T., Nurmi, S., & Veermans, K. (2011). A comparison of students' conceptual understanding of electric circuits in simulation only and simulation-laboratory contexts. *Journal of Research in Science Teaching, 48*(1), 71–93. https://doi.org/10.1002/tea.20386

Jamali, S. M., Ale Ebrahim, N., & Jamali, F. (2023). The role of STEM education in improving the quality of education: A bibliometric study. *International Journal of Technology and Design Education, 33*(3), 819–840. https://doi.org/10.1007/s10798-020-09607-0

Jang, S. J., & Tsai, M. F. (2012). Exploring the TPACK of Taiwanese elementary mathematics and science teachers with respect to use of interactive whiteboards. *Computers & Education, 59*(2), 327–338. https://doi.org/10.1016/j.compedu.2012.02.003

Jia, F., Sun, D., & Looi, C.-K. (2024). Artificial intelligence in science education (2013–2023): Research trends in ten years. *Journal of Science Education and Technology, 33*(1), 94–117. https://doi.org/10.1007/s10956-023-10032-8

Jumayeva, M. B. (2021). Interactive methods used in primary schools. *Scientific Progress, 2*(4), 881–885.

Kalogiannakis, M., Papadakis, S., & Zourmpakis, A.-I. (2021). Gamification in science education: A systematic review of the literature. *Education Sciences, 11*(1), Article 22. https://doi.org/10.3390/educsci11010022

Kandlhofer, M., Steinbauer, G., Hirschmugl-Gaisch, S., & Huber, P. (2016, October). Artificial intelligence and computer science in education: From kindergarten to university. In *2016 IEEE Frontiers in Education Conference (FIE)* (pp. 1–9). IEEE. https://doi.org/10.1109/FIE.2016.7757411

Khasseh, A. A., Amiri, M. R., & Sadeghi, A. (2021). Topic analysis of nursing research using co-word analysis. *Iranian Journal of Nursing and Midwifery Research, 26*(5), 417–424. https://doi.org/10.4103/ijnmr.IJNMR_174_19

Kleminski, R., Kazienko, P., & Kajdanowicz, T. (2022). Analysis of direct citation, co-citation and bibliographic coupling in scientific topic identification. *Journal of Information Science, 48*(3), 349–373. https://doi.org/10.1177/0165551520946642

Kohler, S., & Dietrich, T. C. (2021). Potentials and limitations of educational videos on YouTube for science communication. *Frontiers in Communication, 6*, Article 581302. https://doi.org/10.3389/fcomm.2021.581302

Kraft, R. J. (1990). Experiential learning. In *Adventure education* (pp. 175–183). Kendall/Hunt.

Kutlu-Abu, N., Bozgün, K., & Uluçınar-Sağır, Ş. (2023). Studies on scientific literacy in primary education: A bibliometric and content analysis. *Hungarian Educational Research Journal, 13*, 1–20. https://doi.org/10.1556/063.2023.00039

Lai, A. F., Chen, C. H., & Lee, G. Y. (2019). An augmented reality-based learning approach to enhancing students' science reading performances from the perspective of the cognitive load theory. *British Journal of Educational Technology, 50*(1), 232–247. https://doi.org/10.1111/bjet.12716

Lee, S. Y. (2024). *Developing teacher agency for professional learning and development through an enquiry-based learning approach involving action research* (Doctoral dissertation, University of London, University College London).

Letina, A. (2020). Development of students' learning-to-learn competence in primary science. *Education Sciences, 10*(11), Article 325. https://doi.org/10.3390/educsci10110325

Li, P. H., Lee, H. Y., Lin, C. J., Wang, W. S., & Huang, Y. M. (2025). InquiryGPT: Augmenting ChatGPT for enhancing inquiry-based learning in STEM education. *Journal of Educational Computing Research, 62*(8), 2157–2186. https://doi.org/10.1177/07356331241289824

Lindholm, M. (2018). Promoting curiosity? Possibilities and pitfalls in science education. *Science & Education, 27*, 987–1002. https://doi.org/10.1007/s11191-018-0013-5

Logan, M. (2020). Challenging the anthropocentric approach of science curricula: Ecological systems approaches to enabling the convergence of sustainability, science, and STEM education. In A. Cutter-Mackenzie-Knowles, K. Malone, & E. Barratt Hacking (Eds.), *Research handbook on childhoodnature* (pp. 1181–1208). Springer. https://doi.org/10.1007/978-3-319-67097-1_68

Mansour, N. (2024). Students' and facilitators' experiences with synchronous and asynchronous online dialogic discussions and e-facilitation in understanding the Nature of Science. *Education and Information Technologies, 29*(12), 15965–15997.

Manz, E. (2015). Resistance and the development of scientific practice: Designing the mangle into science instruction. *Cognition and Instruction, 33*(2), 89–124. https://doi.org/10.1080/07370008.2014.1000490

McAllister, J. T., Lennertz, L., & Atencio Mojica, Z. (2022). Mapping a discipline: A guide to using VOSviewer for bibliometric and visual analysis. *Science & Technology Libraries, 41*(3), 319–348. https://doi.org/10.1080/0194262X.2022.2057608

Mee, R. W. M., Yob, F. S. C., Pek, L. S., Abd Rauf, M. F., Mingmei, Y., & Derahvasht, A. (2025). Building digital thinkers: A bibliometric analysis of computational thinking in children's education for a sustainable future. *Contemporary Educational Technology*, *17*(3), Article ep581. https://doi.org/10.30935/cedtech/16309

Mercer, N., Dawes, L., & Staarman, J. K. (2009). Dialogic teaching in the primary science classroom. *Language and Education, 23*(4), 353–369. https://doi.org/10.1080/09500780902954273

Morgan, P. L., Farkas, G., Hillemeier, M. M., & Maczuga, S. (2016). Science achievement gaps begin very early, persist, and are largely explained by modifiable factors. *Educational Researcher, 45*(1), 18–35. https://doi.org/10.3102/0013189X16633182

Murphy, C., Neil, P., & Beggs, J. (2007). Primary science teacher confidence revisited: Ten years on. *Educational Research, 49*(4), 415–430. https://doi.org/10.1080/00131880701717289

National Research Council, National Academy of Sciences, Committee on Science, Engineering, and Public Policy. (1996). *An assessment of the National Science Foundation's Science and Technology Centers Program* (Vol. 193). National Academies Press.

Ord, J. (2012). John Dewey and experiential learning: Developing the theory of youth work. *Youth & Policy, 108*(1), 55–72.

https://doi.org/10.33225/jbse/25.24.756

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Palmer, D. (2006). Durability of changes in self-efficacy of preservice primary teachers. *International Journal of Science Education, 28*(6), 655–671. https://doi.org/10.1080/09500690500404599

Pappas, C. C. (2006). The information book genre: Its role in integrated science literacy research and practice. *Reading Research Quarterly, 41*(2), 226–250. https://doi.org/10.1598/RRQ.41.2.4

Paul, J., Lim, W. M., O'Cass, A., Hao, A. W., & Bresciani, S. (2021). Scientific procedures and rationales for systematic literature reviews (SPAR-4-SLR). *International Journal of Consumer Studies, 45*(4), O1–O16. https://doi.org/10.1111/ijcs.12695

Prahani, B. K., Rizki, I. A., Suprapto, N., Irwanto, I., & Kurtuluş, M. A. (2024). Mapping research on scientific creativity: A bibliometric review of the literature in the last 20 years. *Thinking Skills and Creativity, 52*, Article 101495. https://doi.org/10.1016/j.tsc.2024.101495

Pranckutė, R. (2021). Web of Science (WoS) and Scopus: The titans of bibliographic information in today's academic world. *Publications, 9*(1), *Article* 12. https://doi.org/10.3390/publications9010012

Prastikawati, E. F., Adeoye, M. A., & Ryan, J. C. (2024). Fostering effective teaching practices: Integrating formative assessment and mentorship in Indonesian preservice teacher education. *Indonesian Journal on Learning and Advanced Education, 6*(2), 230–253.

Ramulumo, M. (2024). Exploring the impact of early STEM education on science and visual literacy. *Journal of Education in Science, Environment and Health, 10*(3), 216–229. https://doi.org/10.55549/jeseh.725

Repenning, A., Webb, D. C., Koh, K. H., Nickerson, H., Miller, S. B., Brand, C., ... & Repenning, N. (2015). Scalable game design: A strategy to bring systemic computer science education to schools through game design and simulation creation. *ACM Transactions on Computing Education, 15*(2), Article 11. https://doi.org/10.1145/2700517

Richardson, C. S. (2024). *Examining teachers' perceptions of implementation fidelity of a multi-tiered systems of support framework in an online middle school environment* (Doctoral dissertation, Youngstown State University).

Roche, J., Bell, L., Galvão, C., Golumbic, Y. N., Kloetzer, L., Knoben, N., ... & Massetti, L. (2020). Citizen science, education, and learning: Challenges and opportunities. *Frontiers in Sociology, 5*, Article 613814. https://doi.org/10.3389/fsoc.2020.613814

Rogan, J. M., & Grayson, D. J. (2003). Towards a theory of curriculum implementation with particular reference to science education in developing countries. *International Journal of Science Education, 25*(10), 1171–1204. https://doi.org/10.1080/09500690210145819

Rotgans, J. I., & Schmidt, H. G. (2017). Interest development: Arousing situational interest affects the growth trajectory of individual interest. *Contemporary Educational Psychology, 49*, 175–184. https://doi.org/10.1016/j.cedpsych.2017.02.003

Rutten, N., van Joolingen, W. R., & van der Veen, J. T. (2012). The learning effects of computer simulations in science education. *Computers & Education, 58*(1), 136–153. https://doi.org/10.1016/j.compedu.2011.07.017

Schmidt, J. A., Rosenberg, J. M., & Beymer, P. N. (2018). A person-in-context approach to student engagement in science: Examining learning activities and choice. *Journal of Research in Science Teaching, 55*(1), 19–43. https://doi.org/10.1002/tea.21412

Seneviratne, K., Hamid, J. A., Khatibi, A., Azam, F., & Sudasinghe, S. (2019). Multi-faceted professional development designs for science teachers' self-efficacy for inquiry-based teaching: A critical review. *Universal Journal of Educational Research, 7*(7), 1595–1611. https://doi.org/10.13189/ujer.2019.070703

Singh, V. K., Singh, P., Karmakar, M., Leta, J., & Mayr, P. (2021). The journal coverage of Web of Science, Scopus and Dimensions: A comparative analysis. *Scientometrics, 126*, 5113–5142. https://doi.org/10.1007/s11192-021-03948-5

Su, C. H., & Cheng, C. H. (2015). A mobile gamification learning system for improving the learning motivation and achievements. *Journal of Computer Assisted Learning, 31*(3), 268–286. https://doi.org/10.1111/jcal.12088

Symaco, L. P., & Daniel, E. G. (2018). Curriculum, pedagogy, teacher training, and recent reforms in primary science education. In Y. J. Lee, L. P. Symaco, & E. G. Daniel (Eds.), *Primary science education in East Asia: A critical comparison of systems and strategies* (pp. 215–228). Routledge.

Syofyan, H., Fadli, M. R., Lestari, M. R. D. W., & Rosyid, A. (2025). Optimizing science learning through differentiated models to improve science literacy in the digital era. *Multidisciplinary Reviews, 8*(6), Article 2025182. https://doi.org/10.31893/multirev.2025182

Tinkler, A. S., DeMink-Carthew, J., Smith, C. P., & Tinkler, B. E. (2024). Engaging in reform-oriented collaborative inquiry to advance competency-based learning in teacher education. *ie: Inquiry in Education, 16*(2), Article 3. https://digitalcommons.nl.edu/ie/vol16/iss2/3

Tsaliki, C., Papadopoulou, P., Malandrakis, G., & Kariotoglou, P. (2022). Evaluating inquiry practices: Can a professional development program reform science teachers' practices? *Journal of Science Teacher Education, 33*(8), 815–836. https://doi.org/10.1080/1046560X.2022.2036474

van Uum, M. S., Verhoeff, R. P., & Peeters, M. (2017). Inquiry-based science education: Scaffolding pupils' self-directed learning in open inquiry. *International Journal of Science Education, 39*(18), 2461–2481. https://doi.org/10.1080/09500693.2017.1388940

Vieira, R. M., & Tenreiro-Vieira, C. (2016). Fostering scientific literacy and critical thinking in elementary science education. *International Journal of Science and Mathematics Education, 14*(4), 659–680. https://doi.org/10.1007/s10763-014-9605-2

Wang, S., Chen, Y., Lv, X., & Xu, J. (2023). Hot topics and frontier evolution of science education research: A bibliometric mapping from 2001 to 2020. *Science & Education, 32*(3), 845–869. https://doi.org/10.1007/s11191-022-00335-2

Webb, M., Davis, N., Bell, T., Katz, Y. J., Reynolds, N., Chambers, D. P., & Sysło, M. M. (2017). Computer science in K-12 school curricula of the 21st century: Why, what, and when? *Education and Information Technologies, 22*, 445–468. https://doi.org/10.1007/s10639-016-9493-x

Wu, H., Cheng, K., Tong, L., Wang, Y., Yang, W., & Sun, Z. (2022). Knowledge structure and emerging trends on osteonecrosis of the femoral head: A bibliometric and visualised study. *Journal of Orthopaedic Surgery and Research, 17*(1), *Article* 194. https://doi.org/10.1186/s13018-022-02993-0

Zembal-Saul, C. (2009). Learning to teach elementary school science as argument. *Science Education, 93*(4), 687–719. https://doi.org/10.1002/sce.20325

https://doi.org/10.33225/jbse/25.24.756

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Zhao, L., Yang, M. M., Wang, Z., & Michelson, G. (2023). Trends in the dynamic evolution of corporate social responsibility and leadership: A literature review and bibliometric analysis. *Journal of Business Ethics, 182*(1), 135–157. https://doi.org/10.1007/s10551-021-04998-8

Zohar, A., & Barzilai, S. (2013). A review of research on metacognition in science education: Current and future directions. *Studies in Science Education, 49*(2), 121–169. https://doi.org/10.1080/03057267.2013.847261

Zupic, I., & Čater, T. (2015). Bibliometric methods in management and organization. *Organizational Research Methods, 18*(3), 429–472. https://doi.org/10.1177/1094428114562629

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