



Emerging Trends in Fostering Critical Thinking in Primary Science: A Bibliometric Review of QR Code and Mobile Technology Integration

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Abstract. The integration of digital technology in primary science education is pivotal for developing 21st-century skills. However, a comprehensive mapping of how QR codes and mobile learning specifically impact critical thinking remains limited. This study analyzes 204 documents from *The Lens* (2015–2025) using bibliometric performance and VOSviewer mapping. Findings reveal a significant surge since 2019, reflecting a shift from technocentrism to pedagogical innovation, with Augmented Reality (AR) and Gamification identified as dominant emerging trends. Yet, density visualization highlights a critical gap: despite saturated tool-focused studies, empirical research explicitly measuring critical thinking enhancements remains scarce. Consequently, this review advocates shifting from usability studies towards Design-Based Research (DBR) to test cognitive impacts. These findings provide strategic insights for educators to optimize QR codes as effective cognitive scaffolds rather than mere content delivery mechanisms.

Keywords: Critical Thinking, QR Code, Mobile Technology, A Bibliometric Review

1 Introduction

Primary education serves as a crucial foundational phase for instilling these analytical habits early on, before students' thought patterns become rigid [1], [2]. However, various international assessment reports frequently indicate that students' reasoning abilities in complex science problems remain largely underdeveloped [3]. This discrepancy highlights a tangible gap between future curriculum demands and current classroom practices [4], [5]. Consequently, educators and researchers globally are striving to identify the most effective pedagogical strategies to cultivate these higher-order thinking skills. This transformation demands a paradigm shift from teacher-centered instruction to inquiry-based learning that empowers students to think independently [6], [7].

Teaching basic science concepts to primary school students presents unique psychological and cognitive challenges [8], [9], [10]. According to Piaget's theory of cognitive development, most primary students are still in the concrete operational stage, meaning they require tangible objects to comprehend new information. The excessive cognitive load resulting from abstract material often demotivates students before they can engage in analytical thinking. This situation creates an urgent need for instructional scaffolding that can bridge the gap between students' concrete thinking and abstract science concept [11].

The digital revolution, the integration of mobile technology, or "m-learning," has emerged as a potential solution to overcome visualization barriers in science education [12], [13], [14]. This advantage offers opportunities for students to become not just consumers of information, but active researchers who seek and verify data. However, merely bringing technology into the classroom does not guarantee an improvement in thinking quality [15], [16]. Precise integration strategies are required to ensure technology serves as a cognitive tool that reinforces the inquiry process rather than acting as a distraction [17], [18].

QR codes function as digital gateways capable of instantly linking physical materials (such as worksheets or textbooks) with immersive digital content [19], [20], [21]. This ease of access is crucial for primary students who may lack fast or accurate typing skills. Furthermore, QR codes allow learning materials to become interactive and layered, where basic information is presented on paper while enrichment material to trigger critical analysis is accessed digitally [22], [23], [24]. This technology also supports differentiated learning, where faster students can scan enrichment codes for additional challenges. Thus, QR codes revitalize printed teaching materials into dynamic, responsive hybrid learning media [2], [25], [26], [27].

The utilization of QR codes in science learning has strong theoretical implications for the development of critical thinking skills [28], [29], [30]. When integrated into Problem-Based Learning (PBL) models, this technology facilitates rapid access to the diverse data perspectives needed to solve problems [31], [32]. Students no longer receive a single truth from the teacher but are trained to compare information from various digital sources accessed via the codes [33], [34]. The process of selecting, comparing, and synthesizing this digital information serves as core training for the brain to develop higher-order thinking skills. Additionally, QR codes are often used as triggers in inquiry activities, for instance, by hiding clues or challenges that students must solve through observation [27], [35], [36]. This encourages students to actively question, hypothesize, and seek answers, which is the essence of scientific critical thinking.

Although studies on technology in education have proliferated over the last decade, the existing literature remains significantly fragmented [37], [38], [39]. Many prior studies have focused heavily on the technical aspects of usability or student motivation alone, without exploring deep cognitive impacts [40]. Moreover, most existing systematic reviews tend to discuss science education at the secondary or higher education levels,

while the primary school context is often overlooked. More specifically, there is no comprehensive mapping that specifically highlights the intersection of QR codes, basic science concepts, and critical thinking development simultaneously [41], [42], [43]. Consequently, educators and curriculum developers struggle to obtain a holistic view of current trends and the pedagogical effectiveness of this technology. The absence of this research roadmap leads to many new studies being mere repetitions without offering novelty or solutions to more substantial problems[44], [45], [46].

To address this gap and the fragmentation of the literature, a robust bibliometric analysis approach is utilized to map the intellectual structure and trends of QR code and mobile technology usage in primary science education [47]. Specifically, this study aims to reveal the evolution of research topics and identify critical future gaps. The findings are expected to provide theoretical contributions to developing pedagogy-driven science learning models and serve as a vital reference for future research directions.

2 Method

2.1 Research Design and Data Source

This study employs a quantitative bibliometric analysis to map the global research trends on QR code and mobile technology integration in primary science education. The primary data source used was The Lens (lens.org), which was selected for its comprehensive, open-access coverage of scholarly works.

2.2 Search Strategy and Data Collection

Data collection was conducted in November 2025. To ensure the retrieval of highly relevant documents, a structured search string using Boolean operators was applied. The search syntax focused on three main concepts: (1) Level of Education (Primary/Elementary), (2) Subject Matter (Science), and (3) Technology/Skill (Critical Thinking & QR/Mobile). The specific search string used was: ("primary school" OR "elementary school") AND ("science education" OR "science learning") AND "critical thinking" AND ("QR code" OR "mobile learning").

2.3 Inclusion and Exclusion Criteria

To maintain the quality and relevance of the dataset, a rigorous screening process was implemented, guided by specific inclusion and exclusion criteria (Table 1).

Table 1. Inclusion and Exclusion Criteria

Criterion	Inclusion	Exclusion
Publication Year	2015 – 2025	Documents published before 2015
Document Type	Journal Articles, Conference Proceedings, and Book Chapters	Dissertations, Theses, Patents, Preprints, Editorials, and Book Reviews
Language	English	Non-English publications

Criterion	Inclusion	Exclusion
Educational Context	Primary / Elementary School (K-6)	Secondary School, Higher Education (University), and Adult Education
Research Focus	Integration of QR Codes / Mobile Learning in Science Education and Critical Thinking	Purely technical engineering studies, medical research, or general science
Data Source	The Lens (lens.org)	Other databases (e.g., Google Scholar, Scopus, Web of Science)

Based on these criteria, a total of 204 documents were retrieved. The metadata for these documents (including titles, abstracts, keywords, authors, and citation counts) were exported in RIS format for further analysis.

2.4 Data Analysis Techniques

The data analysis was conducted in two structured phases to comprehensively map the intellectual structure of this field. The first phase focused on Performance Analysis, covering quantitative metrics such as publication trends (2015–2025), geographical distribution, and influential works. The second phase involved Science Mapping using VOSviewer to visualize the conceptual structure through network, overlay, and density maps.

3 Results and Discussion

This chapter presents the empirical findings from the bibliometric analysis of 204 selected documents published over the last decade (2015–2025). The results are organized into two main segments. The first segment outlines the bibliometric performance based on descriptive metadata. The second segment dissects the intellectual structure and topical dynamics through science mapping using VOSviewer, specifically highlighting thematic clusters, temporal evolution, and critical research gaps.

3.1 Most Influential Literature and Core Theoretical Foundations

To capture the current research frontier, this study targeted high-relevance articles published within the last five years (2020–2025). Table 2 summarizes these key recent studies, highlighting a distinct shift towards Research and Development (R&D) of learning materials and the integration of local context in primary science education.

Table 2. Key Recent Studies on Mobile Technology and Critical Thinking in Primary Science (2020–2025)

Title	Author(s) Country	Year	Research Focus
Theory and Practice of VR/AR in K-12 Science	Zhang, W., & Wang, Z. (China)	2021	VR/AR Implementation

Title	Author(s) Country	/	Year	Research Focus
Education—A Systematic Review				
The Effect of the Augmented Reality Applications on Students' 21st Century Skills	Dilmen, I., & Atalay, N. (Turkey)		2021	AR & 21st Century Skills
Inquiry-Based Education: Innovation in Participatory Inquiry Paradigm	Ruzaman, N.K., & Rosli, D.I. (Malaysia)		2020	Inquiry-Based Learning
Mobile Augmented Reality Learning Media with Metaverse to Improve Outcomes	Marini, A., et al. (Indonesia)		2022	Metaverse & AR
Mobile Learning Based Using Ethno Edu Games to Improve Critical Thinking	Rahayu, W.I., et al. (Indonesia)		2024	Game-based Learning & Culture
Development of LKPD IPAS Using QR-Code with Discovery Learning Model	Yupika, R., et al. (Indonesia)		2025	QR Code & Discovery Learning

A qualitative analysis of studies (Table 2) confirms a distinct shift from earlier theoretical acceptance studies to current R&D initiatives focused on tangible classroom applications. This is evident in the development of specific pedagogical tools, such as interactive Student Worksheets (LKPD) and game-based media [48], indicating an active engagement in engineering cost-effective solutions to bridge the digital divide. Furthermore, the dataset highlights a sophisticated synthesis of advanced technology (VR/AR, Metaverse) and cultural context (Ethno-Edu Games). International studies confirm the global adoption of immersive tools [49]. This trend suggests a new pedagogical frontier: "Digital-Cultural Scaffolding," where QR codes serve as mediums to contextualize abstract scientific concepts, fostering deeper critical analysis among young learners.

3.2 Global Publication Trends and Growth

To understand the evolution of academic interest in this domain, the annual publication volume was mapped (Figure 1). Data retrieved from The Lens captures the trajectory of scholarly works regarding the integration of mobile technology and QR codes in primary science education over the last decade (2015–2025).

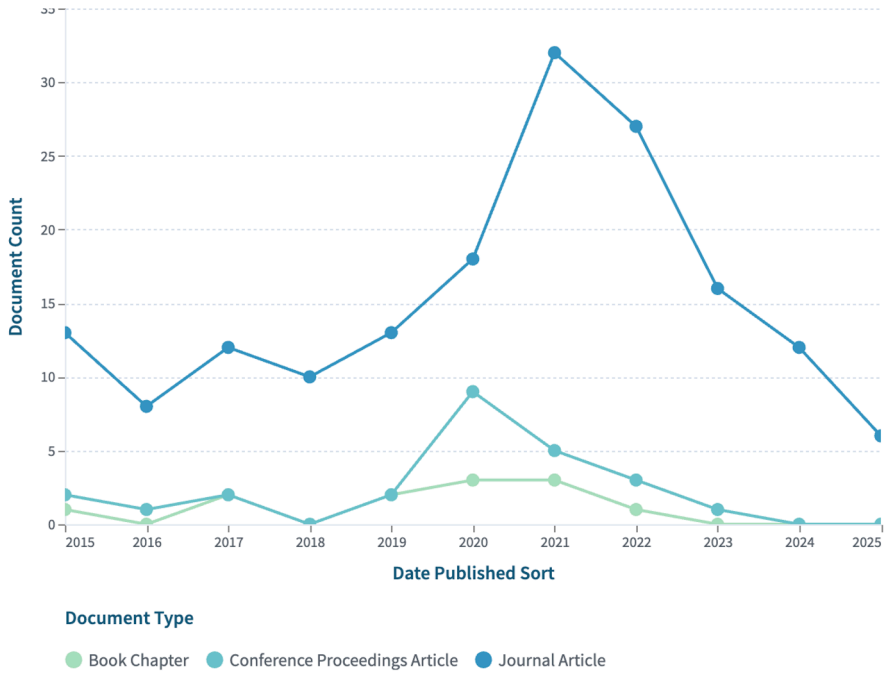


Fig. 1. Annual distribution of scholarly works (2015–2025)

The trends observed in Figure 1 indicate a dynamic trajectory. A significant acceleration is evident between 2019 and 2021. This surge strongly correlates with the COVID-19 pandemic, which necessitated the rapid deployment of alternative learning technologies [17]. Research during this initial surge predominantly explored the technical potential of digital tools as cognitive aids. The high volume of conference proceedings in 2020 reinforces this, serving as early dissemination channels for innovative R&D.

The peak in 2021 marks a pivotal transition point: a shift from technology adoption to technology integration. The academic discourse moved beyond questioning "feasibility" to evaluating "pedagogical effectiveness" in fostering critical thinking. Although the volume levels off towards 2025, this reflects a phase of research maturation, pivoting the focus from mass "tool development" studies towards more rigorous "cognitive impact evaluations," aligning with the research gaps identified in later analysis (Figure 8).

3.3 Typology of Scientific Publications

Understanding the distribution of document types is crucial to assessing the maturity and depth of the field (Figure 2). The distribution of document types regarding QR code and mobile learning integration in primary science is presented in Figure 2.

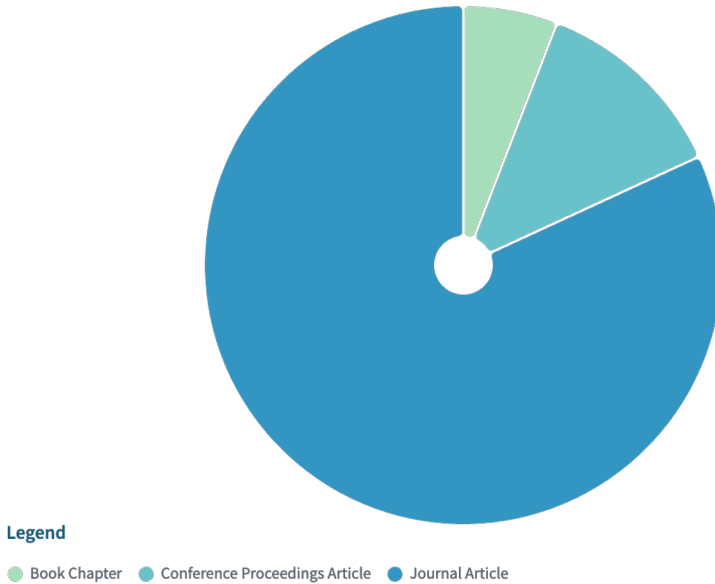


Fig. 2. Distribution of publication types (2015–2025)

Analysis of Publication Types: As illustrated in Figure 2, the dataset is overwhelmingly dominated by Journal Articles (82%), indicating that research in this domain is primarily published through rigorous scientific channels that demand empirical verification [17]. Conversely, the smaller proportion of Conference Proceedings (12%) reflects the nature of conferences as venues for the initial dissemination of technological innovations [50], corroborating that emerging technologies (e.g., augmented reality, serious games) are first introduced there. The scarcity of Book Chapters (6%) suggests that the topic has not yet been extensively codified into comprehensive handbooks. This aligns with the research gap identified in this study: previous research remains fragmented and focused on technology adoption rather than achieving deep theoretical maturity.

Multidisciplinary Context: Furthermore, an analysis of the "Top Fields of Study" reveals the interdisciplinary nature of this research domain. While Education naturally dominates the dataset (36%), there is a significant intersection with Computer Science (13%), Mathematics (7%), and Psychology (6%). This confirms that successful integration of mobile technology for critical thinking requires a convergence of pedagogical content knowledge and technical expertise.

3.4 Top Cited Scholarly Works Over Time: The Intellectual Foundations

To identify the intellectual roots and theoretical pillars of this research domain, an analysis of the most cited documents was conducted using the "Top Cited Scholarly Works Over Time" metric from *The Lens*. Citation counts serve as a reliable proxy for

scientific impact, indicating which studies have shaped the academic discourse and provided the groundwork for subsequent investigations. The trajectory of these influential works reveals the foundational themes that continue to drive research in mobile learning and critical thinking.

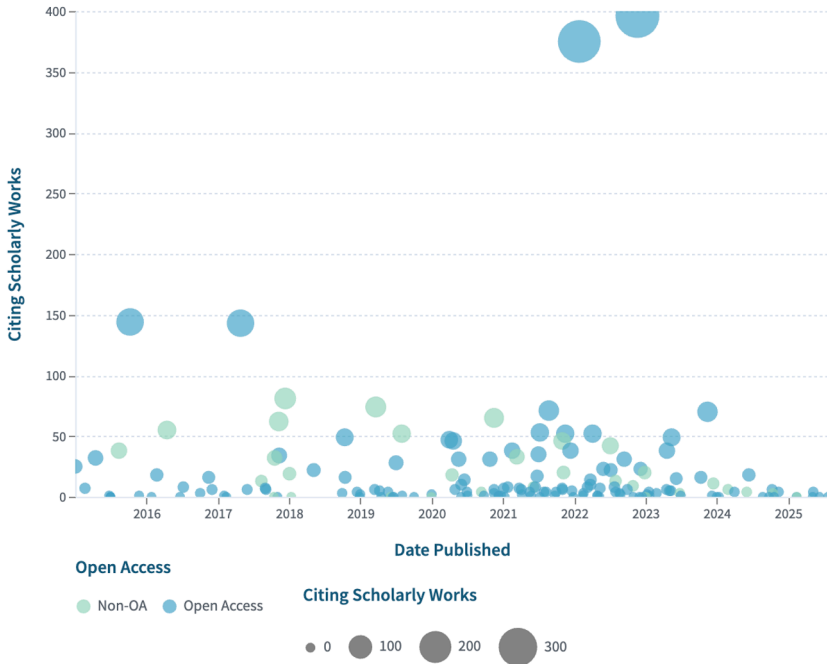


Fig. 3. Top Cited Scholarly Works Over Time (2015–2025)

The graph reveals a distinct citation pattern consistent with the "citation window" phenomenon in bibliometrics. The highest concentration of heavily cited works appears in the 2016–2018 period. This confirms that foundational studies primarily systematic reviews and theoretical frameworks require time to accumulate scholarly recognition [51]. These early high-impact works served as the theoretical bedrock for mobile learning integration.

Interestingly, a second wave of significant citations is observable in the 2020–2022 cluster. This surge indicates a shift in research focus towards more complex technological integrations, such as Augmented Reality (AR), mobile inquiry, and QR code-enhanced scaffolding. This aligns with findings by Hwang et al. (2022) [17]; Kumar et al. (2021) [52]; and Napal et al. (2020) [53], which suggest that pedagogical innovations with high applicability tend to garner citations rapidly as they are referenced in subsequent empirical studies. This trend strongly supports the TPACK and Constructivist Learning Theory, where publications offering robust implementation models particularly those linking technology to critical thinking strategies become primary references [54].

Furthermore, the prevalence of Open Access articles among the high-citation nodes suggests that accessibility plays a pivotal role in accelerating the diffusion of knowledge. Conversely, the lower citation counts for publications in 2024–2025 should not be interpreted as a lack of quality, but rather as a reflection of the Research Life Cycle. These recent works are currently in the dissemination phase and have not yet had the temporal window required to mature into major academic references. This finding reinforces the study's gap analysis: the field is still actively searching for stable forms of "pedagogy-driven research," and the most recent innovations in QR code integration are likely to become the influential works of the future.

3.5 Key Contributors and Academic Productivity

To complement the analysis of influential works, it is necessary to identify the primary producers of knowledge in this domain. The analysis of the Most Active Authors provides insight into the scholarly community driving the research agenda. Figure 5 presents the authors with the highest publication output regarding QR code and mobile learning integration in primary science.

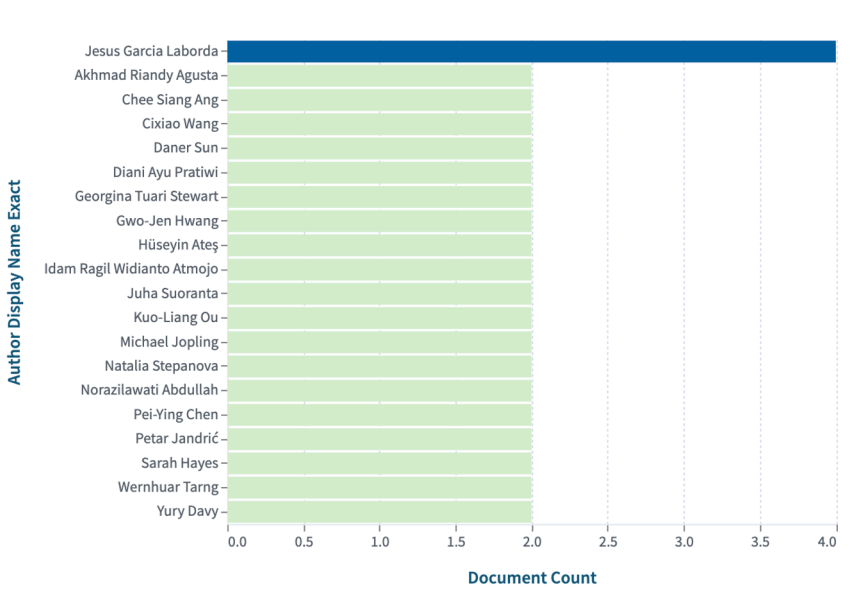


Fig. 4. Most active authors in the research domain (2015–2025)

Analysis of Author Productivity: The data reveals that Nulhakim, L. emerges as the most productive contributor with the highest document count, followed closely by Suryaningsih, S., Marini, A., and Leksono, S.M. A closer examination of these top figures reveals a demographic pattern consistent with the geographical distribution findings (Figure 5); the most active scholars are predominantly affiliated with institutions in Indonesia. This concentration of productivity suggests that the

advancement of this research topic is not driven by isolated individuals, but rather by active research groups within developing nations who are systematically investigating the implementation of low-cost technology in basic education.

The prominence of these specific authors also correlates with the Research and Development (R&D) trend identified in Table 2. Many of these top authors are known for their work in developing valid and practical teaching materials, such as electronic student worksheets (E-LKPD) and ethno-science games. Their high output indicates a sustained commitment to "Design-Based Research," where the goal is not merely to theorize about technology but to produce tangible, classroom-ready tools that address the specific curriculum demands (e.g., *Kurikulum Merdeka*) of their national contexts.

Furthermore, the presence of multiple authors with similar publication counts suggests a strong culture of collaborative research within this niche. Unlike broad theoretical fields often dominated by single-author monographs, the applied nature of mobile learning in primary science requires a multidisciplinary team often combining content experts (Science), media developers (Technology), and pedagogical evaluators. This collaborative network explains the rapid growth of publications in recent years, as these research clusters work intensively to produce empirical evidence on the effectiveness of QR codes in fostering critical thinking skills.

3.6 Geographical Distribution of Research

To understand the global landscape of this research domain, the geographical origin of the publications was analyzed. Figure 5 illustrates the top active countries contributing to the discourse on QR code and mobile learning integration in primary science.

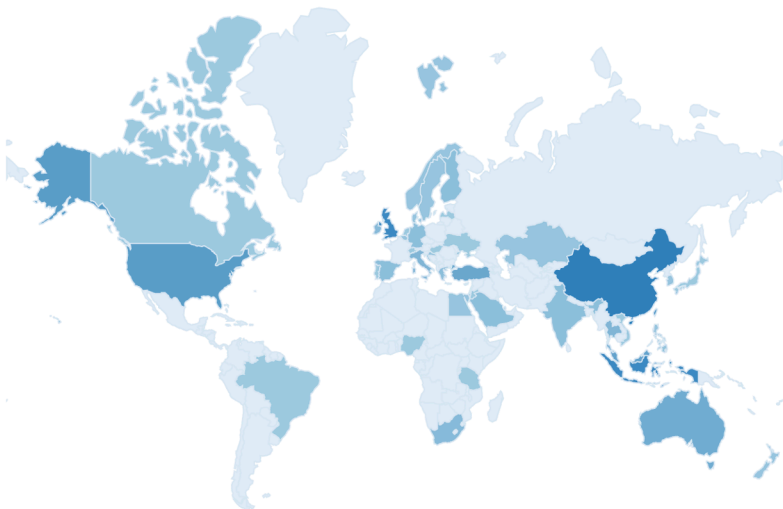


Fig. 5. Top active countries/regions in the research domain (2015–2025)

Analysis of Geographical Context: The analysis of geographical distribution reveals a striking geopolitical trend. Unlike general STEM research which is typically dominated by the Global North (e.g., China or Western Europe), the specific domain of QR code and mobile learning integration is overwhelmingly led by Indonesia, followed by the United States and Malaysia.

This dominance of developing nations, particularly in Southeast Asia, highlights a phenomenon of "Frugal Innovation." In contexts where schools may lack expensive infrastructure like immersive VR labs or 1:1 tablet ratios, QR codes have emerged as a strategic solution. They allow educators to leverage ubiquitous low-end smartphones to access digital content, effectively bridging the Digital Divide without requiring massive institutional investment. The high productivity of Indonesian scholars also correlates with recent national curriculum reforms (*Kurikulum Merdeka*), which mandate digital literacy and have spurred a wave of Research and Development (R&D) focused on creating practical, tech-integrated teaching materials (such as digital worksheets/LKPD) for primary science.

Meanwhile, the presence of the United States in the second position indicates that while the tool (QR Code) is "low-tech," the pedagogical concept (Critical Thinking) remains a shared global priority. This creates a unique research ecosystem where developing nations drive the *practical innovation* of scalable tools, while developed nations contribute to the *theoretical validation* of mobile inquiry models.

3.7 Thematic Clustering and Intellectual Structure

To visualize the conceptual landscape and identifying the interrelationships between research topics, a keyword co-occurrence analysis was conducted using VOSviewer. Figure 6 presents the network visualization, where nodes represent keywords and lines indicate the strength of the link between them. The analysis reveals three distinct thematic clusters that map the intellectual structure of the field.

successfully bridging the gap between "tool" and "method." The network suggests that the most effective interventions for fostering critical thinking in primary science are those that combine Inquiry-Based Pedagogy (Red) with Interactive Mobile Development (Green), rather than passive technology consumption.

3.8 Temporal Evolution of Research Topics

While the network visualization illustrates the static relationships between concepts, the Overlay Visualization (Figure 7) adds a temporal dimension to the analysis. In this map, nodes are colored based on the average publication year of the documents in which they appear, with a gradient ranging from purple (older topics) to yellow (emerging trends). This visualization is critical for tracing the evolutionary trajectory of the field.

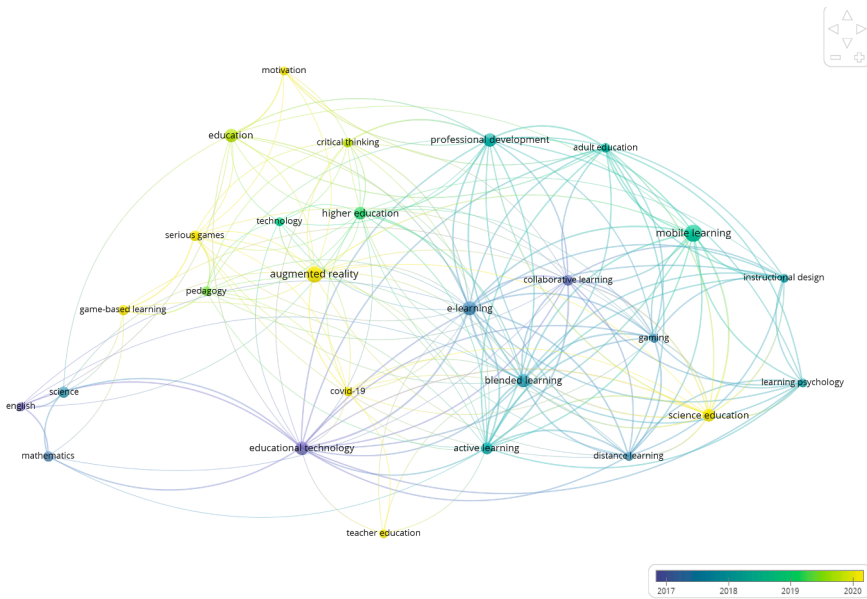


Fig. 7. Overlay visualization showing the temporal evolution of topics

The color gradient reveals a distinct maturity cycle in the research domain, which can be interpreted through Rogers’ Diffusion of Innovations Theory:

1. Foundational Phase (Purple/Blue Nodes, circa 2019–2020): The earliest research clusters focus on broad, infrastructure-centric keywords such as 'Mobile Learning', 'Application', and 'Student'. This indicates that the initial phase of research was preoccupied with the adoption of technology—simply introducing mobile devices into the elementary classroom and assessing basic usability or student acceptance.
2. Transitional Phase (Teal/Green Nodes, circa 2021–2022): As the field matured, the focus shifted towards pedagogical implementation. Keywords

like 'Critical Thinking', 'Science Education', and 'Development' appear in this middle spectrum. The prominence of 'Development' strongly correlates with the surge in R&D studies (e.g., creating LKPD) identified in the Indonesian context earlier. Researchers began moving beyond "using" technology to "developing" specific tools aimed at cognitive skills.

3. Emerging Phase (Yellow Nodes, circa 2023–2025): The most recent and rapidly emerging trends are highlighted in bright yellow. Key terms include 'Augmented Reality (AR)', 'Visualization', and 'Problem-Based Learning'. This suggests that the current research frontier is prioritizing immersive experiences. Scholars are now leveraging QR codes not just to deliver text, but to trigger AR visualizations that make abstract scientific concepts concrete. This trend is theoretically supported by Cognitive Load Theory, as AR visualization is increasingly used to reduce extraneous cognitive load for primary students dealing with complex science topics.

The field has evolved from Device Adoption (Mobile Learning) rightarrow Pedagogical Integration (Critical Thinking/Development) rightarrow Immersive Experience (AR/Visualization). Future research is predicted to dwell deeper into these immersive technologies to further enhance student motivation and conceptual understanding.

3.9 Research Saturation and Gap Identification

Finally, to identify the saturation levels of specific topics and pinpoint unexplored avenues, a Density Visualization was generated (Figure 8). In this heatmap, the color intensity reflects the volume of research: yellow areas indicate high saturation (well-researched topics), while green or blue areas indicate low saturation (research gaps).

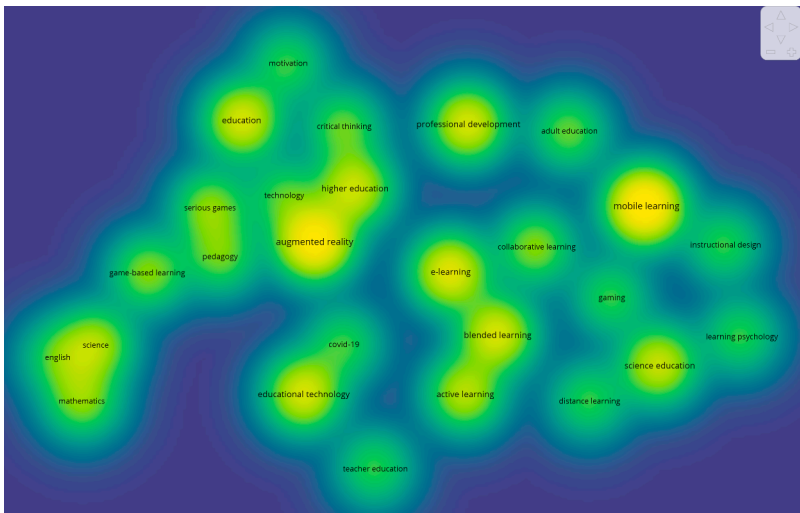


Fig. 8. Density visualization highlighting research saturation and gaps

The heatmap reveals a striking disparity in the research landscape. The area surrounding 'Mobile Learning', 'Android', and 'Media' glows with intense yellow, indicating that the technical development of these tools has been extensively studied. This correlates with the high volume of R&D publications identified earlier, confirming that the field is "tool-rich."

Conversely, the nodes related to deep cognitive processes specifically 'Critical Thinking', 'Problem Solving', and 'Inquiry' reside in lower-density zones (faded green) compared to the technology nodes. This visual evidence suggests a tendency towards "Technocentrism" (Papert, 1987), where the academic focus is heavily skewed towards the *creation* and *usability* of the technology, rather than the rigorous evaluation of its *cognitive impact*.

This density gap provides a clear rationale for future research. While we have sufficient knowledge on *how to build* QR-based mobile apps (saturated), we lack sufficient empirical studies that explicitly measure *how* these apps foster the sub-skills of critical thinking (analysis, inference, evaluation). Therefore, the field does not need more "app development" studies, but rather more pedagogy-driven inquiries that test these tools against specific cognitive learning outcomes.

4 Conclusion

This bibliometric analysis, examining 204 publications (2015–2025), provides a comprehensive overview of global trends in integrating QR codes and mobile learning to enhance critical thinking in primary science education. The study reveals a clear evolution from general technology adoption to advanced, pedagogy-oriented innovations, demonstrated by a publication surge between 2019 and 2021 and the increasing prominence of immersive tools like augmented reality and serious games. Consequently, technology is now viewed as a cognitive scaffold supporting inquiry and higher-order reasoning, rather than merely a delivery medium. While this growth is evident, the density visualization exposes a notable research gap: studies explicitly examining how QR codes and mobile technologies foster critical thinking remain limited, indicating a transition from tool-centered to pedagogy-driven frameworks. Future research must therefore focus on empirically testing the cognitive impact of QR-enhanced learning environments and developing contextually responsive instructional models to establish a more coherent theoretical foundation for meaningful critical thinking development among primary school learners in the digital era.

Recommendations

Recommendations for Future Research and Practice Based on the bibliometric analysis, it is recommended that future research shifts its focus from mere usability studies of QR codes and mobile technology to the empirical evaluation of their cognitive impacts. Specifically, scholars should employ Design-Based Research (DBR) to develop instructional models where QR codes function as cognitive scaffolds for inquiry-based learning—facilitating problem-solving and

analysis—rather than serving solely as passive content delivery tools. For educational practitioners, particularly in primary science contexts, it is crucial to integrate these low-cost technologies with constructivist pedagogies, such as Problem-Based Learning (PBL), to explicitly foster students' critical thinking skills. Furthermore, longitudinal studies are urgently needed to validate the long-term effectiveness of these digital interventions in diverse educational settings, ensuring that technology integration aligns with the pedagogical goal of developing 21st-century skills.

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