

Research Trend Bi-Model Media in Science Education: Bibliometric Analysis

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Abstract. This study analyzes the global development and research trends of bi-model media in science education using a bibliometric approach. Data from the Scopus database were processed with Biblioshiny and VOSviewer to identify the conceptual structure, thematic clusters, and emerging directions. The results show that e-learning, virtual reality, and students are dominant themes driving a shift toward interactive and learner-centered education, while artificial intelligence, machine learning, and social media form the foundation for developing data-driven adaptive learning systems. The thematic and keyword network analyses indicate a growing transition toward a hybrid framework that integrates technology, pedagogy, and human experience. The findings highlight the importance of aligning pedagogical design with intelligent technological support to create meaningful, adaptive, and context-based learning experiences. Although limited to a single bibliographic source, this study contributes significantly to mapping the research landscape of bi-model media and offers insights for future studies on AI-based integration, learning analytics, and equitable access to digital education in the 21st century. Unlike previous bibliometric studies that broadly examine digital or technology-enhanced learning, this work uniquely foregrounds the emerging concept of bi-model media, providing a sharper lens to understand how dual-mode representations shape scientific understanding and instructional innovation.

Keywords: *bi-model media, science education, bibliometric analysis, trend.*

INTRODUCTION

The development of information and communication technology (ICT) over the past few decades has brought significant changes to the field of education. One notable advancement is the utilization of virtual media in the learning process, particularly at the elementary school level. Virtual media offer unique capabilities to provide interactive, immersive, and engaging learning experiences by integrating digital visual elements with real-world learning contexts (Vatananan-thesenvitz, 2019)(Flegr, 2022; Gustav et al., 2022). In the context of elementary education, the use of virtual media can bridge the gap between theory and practice by helping students visualize abstract concepts that are difficult to comprehend through textbooks alone (Yang et al., 2024).

One of the most prominent innovations in this area is the integration of real and virtual media into a bi-model media approach, which facilitates richer and more contextualized learning experiences. This approach, particularly relevant for elementary education, provides learning experiences that go beyond traditional textbooks and media by combining real objects with interactive digital simulations within a single learning sequence.

The integration of real (concrete) media and virtual media optimizes the learning experience in elementary education. Real media provide a foundation of concrete experiences through physical and manipulable objects or models, while virtual media extend the range of representations through digital simulations and visualizations that facilitate the understanding of abstract concepts. This combination makes learning more interactive, immersive, and contextual. Empirical evidence indicates that combining real and virtual experiments consistently enhances conceptual understanding and science learning outcomes (Wörner & Scheiter, 2022; Flegr et al., 2023; Wang et al., 2025). For young learners at the elementary level, digital simulations have been shown to support the introduction of basic scientific concepts and provide exploration opportunities that are difficult to achieve using physical tools alone (Falloon, 2019).

In general, combining direct interaction with digital experiences yields better learning outcomes than purely face-to-face instruction, reinforcing the rationale for bi-model integration in elementary education settings (Schmid et al., 2023). Moreover, recent studies on immersive ecosystems (VR/AR) have demonstrated similar benefits in terms of motivation, engagement, and learning experiences findings that are particularly relevant when the virtual component of the bi-model is implemented through immersive simulations (Lampropoulos, 2024; Matovu et al., 2023). Consequently, the bi-model media approach facilitates learning that is concrete, representational, and reflective. Real media foster experience-based understanding, while virtual media deepen and bridge abstraction and the scale of phenomena, ultimately strengthening motivation, engagement, and science achievement in elementary education (Wörner & Scheiter, 2022).

The bi-model media approach, which integrates the use of real and virtual media, has emerged as an important focus in science education research due to its ability to provide multimodal learning experiences that enrich students' interactions with abstract objects and phenomena. Several empirical studies have demonstrated that the combination of these two types of media can deepen conceptual representations and enhance the quality of students' cognitive engagement (Wörner & Scheiter, 2022; S. Wang et al., 2024). Learning that combines physical experimentation with digital simulations has also been reported to strengthen scientific understanding, reasoning, and knowledge transfer across contexts (Flegr, 2022; Matovu et al., 2023). Systematic reviews further confirm that such multimodal instructional designs significantly improve students' conceptual understanding and scientific thinking skills (Vatananan-thesenvitz et al., 2019).

On the other hand, bibliometric analysis has been increasingly utilized in science education to map the evolution of research, identify patterns of collaboration among authors, and trace emerging topics and research directions (Donthu et al., 2021). Through this approach, researchers can gain a broader understanding of the scientific landscape, including publication growth, citation dynamics, and global knowledge networks. However, despite the rapid expansion of studies on digital learning, virtual environments, and multimodal instructional design, bibliometric analyses that specifically and comprehensively examine *bi-model media* in science learning remain very limited. Existing reviews tend to address broader themes such as digital pedagogy or hybrid learning without isolating how dual mode representations (real and virtual media combined) are conceptualized, evolve over time, and contribute to science learning processes. This indicates a clear and significant research gap, particularly in the context of elementary science education where multimodal and immersive learning models are increasingly emphasized. Addressing this gap is essential to understand how the field has developed, where current research is concentrated, and what directions are emerging for the future. Therefore, this study seeks to fill the gap by conducting a focused bibliometric analysis on bi-model media, offering a systematic mapping of its development, research trends, and potential future trajectories in science education. To achieve this, the following research questions are proposed:

RQ1: Which countries have the highest citation impact in the field of *bi-model media* research within science education?

RQ2: What are the thematic development, evolution, and map?

RQ3: What are the keyword trends and network visualization?

METHODOLOGY

This study employed a bibliometric approach using data retrieved from the Scopus database, which is widely recognized for its extensive coverage of high-quality scientific publications (Pranckut, 2021). Bibliometric analysis was selected because it enables researchers to map citation patterns, thematic evolution, and structural development of a research field, thereby offering a comprehensive and reproducible overview of scholarly trends (Donthu et al., 2021; Zaidi et al., 2025).

Data Processing and Screening

The dataset was collected from Scopus using the keywords related to dual-mode and bi-model media, focusing on the publication period 2015–2025. To ensure consistency and comparability, the search was limited to peer-reviewed journal articles written in English, as this document type most frequently contains original and citable research contributions. A PRISMA-based screening procedure (Page et al., 2021) was applied to remove irrelevant records and duplicates. After screening, a total of 91 articles were retained for analysis and exported in CSV format for further processing. Figure 1 shows the entire selection procedure in accordance with PRISMA criteria (Page et al., 2021).

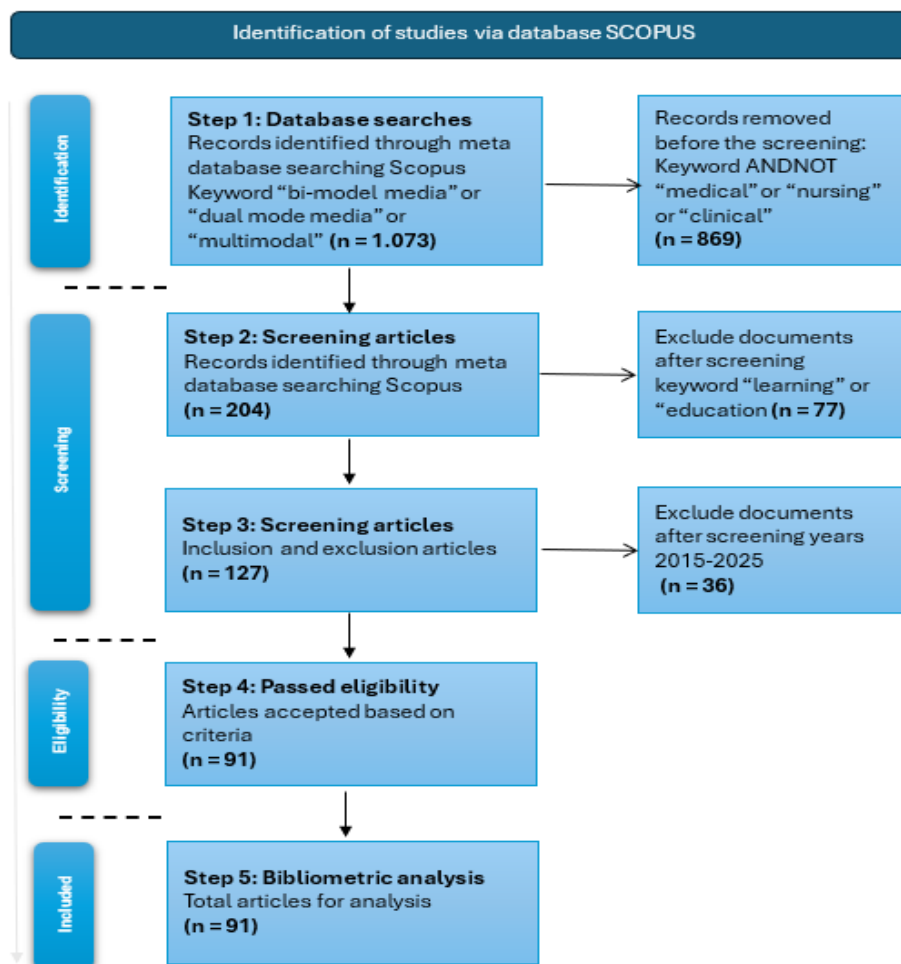


Figure 1. The proses of article selection

Prior to analysis, metadata were cleaned to ensure accuracy and uniformity. Standardized Scopus metadata including authors, affiliations, keywords, abstracts, journals, countries, and

citations were used to support transparent and replicable procedures. The final dataset was stored and organized in CSV and Excel formats to facilitate cross-platform compatibility.

Data analysis

Multiple software programs are used for bibliometric analysis to provide a more engaging presentation. The Biblioshiny program has to be coded in the R Studio application in order to be called. The R program, which is based on the open-source bibliometric package created by (Aria & Cuccurullo, 2017), may be used to perform bibliometric analysis and visualize the data. Through program calls from the R application, researchers may do bibliometric analysis interactively with Biblioshiny, an online version of the Bibliometrix package (Aria & Cuccurullo, 2017). After importing data in CSV format, users may do a variety of analyses, including network, theme, and research trend analysis, and quickly create reports and visualizations. VosViewer is another program used for comparable analysis. The Scopus database is available in CSV and Ris formats for Vosviewer. To examine more specific patterns and carry out more mapping, the author did, however, additionally convert the CSV database format file into Microsoft Excel. As previously stated, there are 91 in this dataset.

RESULTS AND DISCUSSION

Main information

Bibliometric analysis serves not only to identify research trends and productivity but also to illustrate the geographical distribution of scientific influence among countries. Through citation analysis, it becomes possible to determine the extent to which each nation contributes to the global development of knowledge, particularly in the field of *bi-model media* within science education. This information reflects the degree of academic recognition and relevance achieved by researchers from different regions.

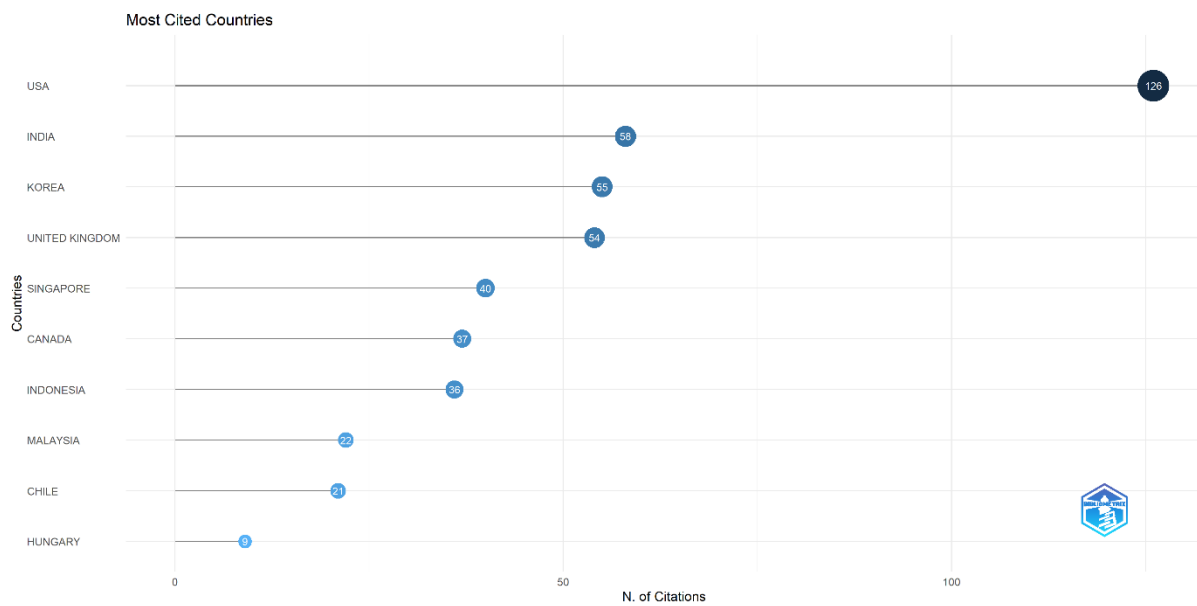


Figure 2. The distribution of the most cited countries

Accordingly, Figure 2 the distribution of the most cited countries contributing to the bi-model media research domain. The visualization reveals that the United States ranks first with a total of 126 citations, followed by India (58), Korea (55), and the United Kingdom (54). Interestingly, several Asian countries including Singapore (40), Indonesia (36), and Malaysia (22) also appear as influential contributors in the global citation network. These results indicate a shifting research dynamic toward Asia, emphasizing the growing scientific visibility of developing nations such as Indonesia in advancing hybrid and multimodal learning media that bridge real and virtual environments.

Bibliometric analysis plays a crucial role in uncovering research dynamics and patterns of scientific influence at the global level. One of the key indicators in this process is the number of citations received by publications originating from various countries. Citation performance serves as an important measure of academic recognition and research relevance. In this study, citation analysis was conducted to evaluate the global impact and contribution of different countries to the advancement of *bi-model media* research in science education (Jan & Ludo, 2010).

Figure 2 illustrates the top ten most cited countries contributing to the field of bi-model media. The analysis reveals that the United States ranks first with 126 total citations, highlighting its dominant role in global knowledge dissemination. Following closely are India (58 citations), Korea (55 citations), and the United Kingdom (54 citations), suggesting that bi-model media

research has expanded beyond the United States and gained strong traction in both Asian and European regions (Kewalramani et al., 2024).

Moreover, several Asian countries notably Singapore (40 citations), Indonesia (36 citations), and Malaysia (22 citations) demonstrate increasing scholarly visibility. This indicates that Southeast Asia has begun to emerge as an influential contributor in the global research landscape, particularly in technology-enhanced and hybrid learning studies. Indonesia's position, ranking seventh overall, signifies a rapid rise in international recognition and impact among developing nations. Meanwhile, Canada (37 citations), Chile (21 citations), and Hungary (9 citations) complete the list, reflecting diverse regional participation and cross-continental collaboration in bi-model media research (Pavlou & Zacharia, 2024).

Overall, the results suggest a notable shift of research influence from Western to Asian countries, emphasizing the growing importance of collaborative, technology-driven educational innovation. This trend underscores that *bi-model media* has evolved into a globally interconnected and multidisciplinary research domain, with Asia particularly Indonesia emerging as one of its significant contributors.

Thematic Evolution and Research Trends

The thematic map illustrates the conceptual structure and developmental trends of research in *bi-model media* within the context of science education. The map is organized into four quadrants, each representing a different level of thematic development and centrality: Motor Themes, Basic Themes, Emerging or Declining Themes, and Niche Themes. This analysis provides a comprehensive overview of how research topics have evolved and how they are positioned within the broader academic discourse.

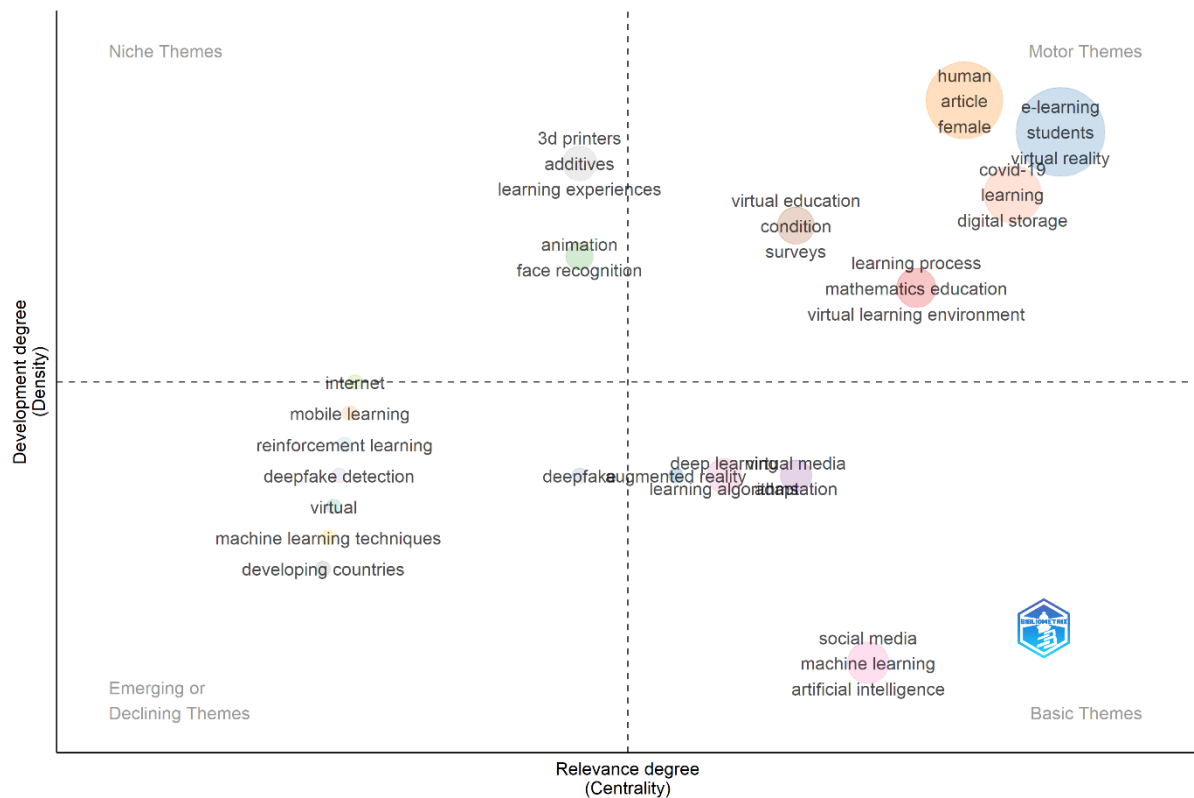


Figure 3. Thematic Evolution and Research Trends

The upper right quadrant (Motor Themes) contains topics with both high centrality and high density, indicating that these are well developed and highly relevant research themes driving the field. Keywords such as *e-learning*, *students*, *virtual reality*, *learning*, and *digital storage* dominate this cluster, signifying that the current focus of *bi-model media* research is centered on technology enhanced learning environments and student engagement through virtual platforms. The inclusion of *COVID-19* in this cluster reflects the significant shift in educational practices during and after the pandemic, which accelerated the adoption of hybrid and virtual learning modes.

In contrast, the lower right quadrant (Basic Themes) represents fundamental but less developed topics that form the conceptual foundation of the field. Terms such as *social media*, *machine learning*, and *artificial intelligence* suggest that these technologies serve as supporting frameworks for future innovation in bi-model and multimodal learning research. Their positioning indicates that while these themes are conceptually central, they are still evolving in application and integration within science education.

The lower left quadrant (Emerging or Declining Themes) includes topics like *mobile learning*, *reinforcement learning*, *developing countries*, and *deepfake detection*. These keywords

represent emerging or context-specific research areas that are still in the exploratory phase or showing limited academic engagement. The presence of *developing countries* highlights a growing interest in understanding how bi-model and technology-driven education can be adapted to diverse socioeconomic contexts, particularly within the Global South.

Finally, the upper left quadrant (Niche Themes) contains specialized yet mature research areas such as *3D printers, animation, learning experiences, and face recognition*. These themes exhibit high internal coherence but limited global connectivity, indicating that they contribute to specific domains of practice particularly in developing immersive and interactive educational experiences rather than defining the central trajectory of the field.

The thematic map analysis reveals the evolution and intellectual structure of *bi-model media research* in science education. The four quadrants Motor Themes, Basic Themes, Emerging or Declining Themes, and Niche Themes provide an integrative overview of dominant topics and their developmental trajectories within the global research landscape.

The Motor Themes, represented by *e-learning, students, virtual reality, learning, and digital storage*, highlight that recent studies emphasize technology enhanced learning environments and virtual interactivity. This finding aligns with Dhawan (2020), who observed that the COVID-19 pandemic accelerated the transformation of educational delivery toward hybrid and online modalities. The prominence of *virtual reality (VR)* further underscores its growing role in enhancing learners' engagement and practical competencies (Yang et al., 2024; (Zawacki-richter et al., 2019). Thus, VR and e-learning serve as the driving forces behind the paradigm shift toward multimodal and bi-model learning frameworks.

Machine learning, artificial intelligence, and social media constitute the Basic Themes, indicating their conceptual centrality but developing maturity. Systematic reviews (S. Wang et al., 2024) emphasize that AI applications in higher education ranging from adaptive learning systems to predictive analytics hold promise but face ethical and pedagogical challenges. This suggests that AI and ML serve as the technological backbone for adaptive and personalized bi-model media in education.

Topics such as *mobile learning, reinforcement learning, developing countries, and deepfake detection* are positioned within Emerging or Declining Themes, indicating exploratory or context-dependent domains. The inclusion of *developing countries* points to a growing concern for equitable access and contextual adaptation of bi-model learning (Dhawan, 2020). Meanwhile, the emergence of *reinforcement learning and deepfake detection* represents cross

disciplinary experimentation, signaling potential future directions toward intelligent evaluation and personalized feedback mechanisms.

Themes like *3D printers, animation, learning experiences, and face recognition* occupy the Niche quadrant, characterized by internal coherence but limited cross linkages. These specialized studies focus on immersive, visual, and experiential learning designs, which contribute practical innovations to science education despite limited integration into mainstream discourse (Aria & Cuccurullo, 2017; Vatananan-thesenvitz et al., 2019). Such themes enrich pedagogical design, particularly in project based and virtual laboratory contexts.

Overall, the thematic landscape indicates a shift from technological exploration toward learner centered pedagogical integration. Practical implications include:

1. Bi-model learning designs should integrate immersive technologies (VR/AR) with scientific reasoning and formative assessment tasks.
2. AI and ML should be leveraged to develop adaptive and data-driven learning systems for personalization.
3. Cross-national collaboration is crucial to bridge digital infrastructure gaps and promote equitable innovation (Donthu et al., 2021).

Future research should focus on developing AI-driven bi-model media frameworks that holistically integrate real and virtual learning experiences, incorporating cognitive, affective, and social learning dimensions. This direction will strengthen both theoretical contributions and practical impact in digital science education.

The keyword trends and network visualization

This visualization illustrates the conceptual relationships and thematic interconnections among research topics related to *bi-model media* in science education. Figure 4 presents the keyword co-occurrence network map generated through bibliometric analysis using *VOSviewer*.

technology-mediated learning. This indicates a growing recognition that *bi-model media research* extends beyond technology design to address human experience and learner characteristics (Dhawan, 2020).

3. Cluster 3 (Blue) – Supporting technologies and data analytics: Containing keywords such as *machine learning*, *social media*, and *questionnaire*, this cluster signifies the data-driven turn in education, where algorithms and analytics are applied to personalize and optimize learning experiences (S. Wang et al., 2024; Zawacki-richter et al., 2019).
4. Cluster 4 (Yellow) – Pedagogical and instructional design themes: Keywords such as *teaching*, *teaching-learning*, *teaching and learning process*, and *education computing* are grouped here, highlighting the pedagogical frameworks underpinning bi-model media applications. This cluster bridges technology implementation with effective instructional practices in science education (Donthu et al., 2021).

The interconnections among clusters indicate that *education* serves as a central linking node, integrating technological, pedagogical, and human-centered dimensions within the global research network.

Therefore, the keyword co-occurrence analysis demonstrates that *bi-model media research* in science education is evolving toward a holistic hybrid approach, combining technological innovation (AI, VR), pedagogical integration (teaching-learning), and human experience (user centered design). These findings align with global bibliometric studies emphasizing the synergistic relationship between pedagogy and technology in fostering adaptive and meaningful learning in the digital era (Aria & Cuccurullo, 2017; Donthu et al., 2021).

Pedagogical and Curriculum Implications

The results of this bibliometric study provide several important implications for pedagogical practices, curriculum development, and educational policy in the context of science education. The four major thematic clusters identified E-learning and VR, Human-centered learning, Data analytics, and Pedagogical design serve as an integrative framework for understanding how bi-model media can transform teaching and learning processes.

1. The dominance of E-learning and VR themes signifies the increasing relevance of immersive technologies in supporting students' conceptual understanding of abstract scientific phenomena. Science educators are encouraged to incorporate dual-mode

learning resources combining real objects, simulations, and virtual manipulatives to promote deeper cognitive engagement and enhance visualization of complex concepts. Human-centered themes further indicate the need for differentiated instruction, where bi-model media should be adapted to students' prior knowledge, learning styles, and demographic characteristics. This highlights the role of teachers in selecting and designing learning experiences that are inclusive, context-responsive, and aligned with learners' diverse needs.

2. The emergence of machine learning, social media, and broader data analytics tools suggests that future science curricula should integrate data driven instructional components. Learning analytics can support ongoing formative assessment, enabling educators to monitor students' progress in real time and adjust instruction accordingly. Curriculum developers should prioritize the integration of hybrid learning models that connect physical experiments with virtual simulations, ensuring that scientific inquiry remains central to the learning process. Furthermore, the presence of niche technologies such as animation, 3D printing, and virtual laboratories indicates opportunities to embed experiential and project-based learning modules within science curricula.
3. The shifting research influence toward Asian and developing countries underscores the urgent need for equitable digital infrastructure and capacity-building initiatives. Policymakers should ensure that schools, especially in underserved regions, have access to reliable internet, digital devices, and emerging educational technologies to support the adoption of bi-model media. Professional development programs must be strengthened to prepare science teachers for the pedagogical integration of VR, AI, and multimodal tools. Policies should also encourage cross-institutional and international collaboration in technology-enhanced science education, fostering innovation that aligns with global digital transformation.
4. To maximize the impact of bi-model media, educational systems must adopt a holistic implementation strategy that bridges technology, pedagogy, and human experience. This includes establishing standards for ethical and effective use of AI in classrooms, integrating hybrid learning competencies into teacher training standards, and developing curriculum guidelines that clearly articulate how real-virtual integration supports inquiry, scientific reasoning, and problem-solving skills. A long-term policy agenda should aim to cultivate digital scientific literacy not only for students but also

for teachers and administrators, ensuring sustainable use of bi-model media in science education.

Overall, these pedagogical and curriculum implications suggest that bi-model media should not be viewed merely as technological tools but as catalysts for transforming instructional models, informing curriculum reform, and shaping educational policy toward more adaptive, equitable, and future-ready science learning ecosystems.

CONCLUSION

This bibliometric study provides a comprehensive overview of the development and research trajectory of *bi-model media* in science education. The findings highlight *e-learning*, *virtual reality*, and *students* as dominant themes driving a paradigm shift toward interactive, learner-centered models, while *artificial intelligence* and *machine learning* serve as the technological foundations for adaptive learning systems.

The results emphasize that the effectiveness of educational media depends not solely on technology but on the integration of pedagogy, human experience, and intelligent technological support. Practically, educators and curriculum designers are encouraged to adopt *bi-model approaches* that combine real and virtual learning environments to enhance engagement, motivation, and conceptual understanding.

Future studies should further explore the integration of bi-model media with data-driven and learning analytics approaches, while addressing ethical considerations, digital readiness, and equity of access across diverse educational contexts.

This study's limitation lies in its reliance on a single bibliographic database (e.g., Scopus), which may not capture the full spectrum of global publications. Nevertheless, it contributes valuable insights into the conceptual structure, thematic evolution, and future directions of bi-model media research as an innovative pedagogical strategy for 21st-century science education.

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