Studies in Bibliometrics of Education and Technology
Homepage: https://scie-journal.net/index.php/SiBET
Email:

p-ISSN:XXXXX; e-ISSN: XXXXX
SiBET, Vol. 1, No. 3, August 2026
Page 17-26
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Mapping the Research Landscape of Technology-Integrated STEAM Education: A Bibliometric Analysis

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Article Info

Article history:

Received: 31 June 2026
Revised: 11 July 2026
Accepted: 25 July 2026
Available Online: 31 July 2026

Keywords:

Bibliometrics
Biblioshiny
Educational Technology
Multicultural Science Education
STEAM
VOSviewer

ABSTRACT

The integration of digital technology and the STEAM approach has shifted science education toward more interdisciplinary, learner-centered, and contextual learning. However, research regarding technology integration, STEAM, and multicultural perspectives in science education remains fragmented across various areas of study; consequently, the field's evolution, dominant themes, inter-theme relationships, and emerging research directions have not yet been comprehensively mapped. This study aims to map the development of research on technology-integrated STEAM education, identify dominant themes and their interrelationships, and pinpoint emerging themes and research gaps to guide future inquiry. A descriptive quantitative approach was employed, utilizing bibliometric analysis of Scopus-indexed scientific publications from 2015 to 2026. Data were analyzed using Biblioshiny and VOSviewer to identify publication trends, keyword co-occurrence, research clusters, and thematic relationships. The analysis reveals that STEAM is the primary theme within the research network, with strong connections to creativity, innovation, science learning, learners, e-learning, game-based learning, augmented reality, design thinking, and sustainability. The findings also indicate a shift from conventional science education toward technology-supported, interdisciplinary, and learner-centered learning. The novelty of this study lies in its mapping of the interconnections between STEAM, digital technology, and multicultural perspectives within a unified research landscape, elements that have historically been studied in isolation. The study implies that future science education research should strengthen the integration of digital technology, local cultural and multicultural contexts, sustainability issues, and the STEAM approach to foster science learning that is more contextual, inclusive, innovative, and relevant to 21st-century needs.

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INTRODUCTION

21st-century education requires students not only to master academic concepts but also to interact in a culturally diverse society (Putri et al., 2022). Science education plays an important role in developing scientific literacy and strengthening multicultural values. Indonesia, as a multicultural country, faces challenges in implementing education that can accommodate ethnic, linguistic, religious, and cultural diversity (Casto, 2022). Various studies show that multicultural education still requires strengthening in learning practices to be able to answer the needs of society (Marosi et al., 2021). Science learning that integrates cultural perspectives is able to help students understand scientific phenomena in a more contextual and inclusive manner (Tilsen et al., 2021). The increasingly complex cultural diversity due to globalization makes multicultural education a basic need in the modern education system. Multicultural education not only focuses on recognizing cultural differences, but also encourages the creation of attitudes of tolerance, equality, and respect for diversity in the learning environment (Nisa' et al., 2024).

On the other hand, the development of digital technology has significantly changed the learning paradigm. Technology allows students to access a wider range of learning resources (Chen et al., 2021),

collaborate virtually, and gain a more interactive learning experience than conventional learning (Ozyurt & Ayaz, 2022). Integrating technology in education provides a strong opportunity to support the implementation of multicultural education (Yulianti et al., 2024). Through digital platforms, students can explore various cultural perspectives, communicate with different groups, and develop cross-cultural understanding more effectively (Smith et al., 2022). In science learning, technology such as virtual simulations, digital laboratories, interactive multimedia, and project-based learning has been shown to increase student engagement (Stepp & Brown, 2021). Technology also makes it possible to integrate local cultural context into science material, making learning more meaningful. The development of STEM and STEAM concepts further strengthens the relationship between science, technology, and society's social needs (Marini et al., 2025). This approach emphasizes the importance of solving real problems that involve various perspectives, including cultural and social aspects in the learning process (Jackson & Cheng, 2022).

Various studies show that the integration of technology in science education has continued to increase in the last decade. This is marked by the increasing number of publications discussing mobile learning, gamification, digital learning, and the use of artificial intelligence in education (Hutomo et al., 2022). Increasing attention to multicultural education and technology is also reflected in the development of international scientific publications (Deák & Kumar, 2024). Bibliometric research shows that the topic of multicultural education has experienced quite significant growth in the last few decades (Mahendra & Maftuh, 2023a). Bibliometric studies are an effective approach for mapping the development of a research field. Through bibliometric analysis, researchers can identify publication trends, prolific authors, dominant countries, collaboration networks, and emerging research themes (Jantakoon et al., 2024). Although research on multicultural education has developed, studies that specifically link multicultural science education with technology support are still relatively limited (S. Hasanah et al., 2022).

Most research still focuses on pedagogy, curriculum, or technology integration in general, without comprehensively examining the relationship among the three. These limitations indicate research gaps that need to be explored further (Hasanah et al., 2023). Identifying research trends in the field of technology-based multicultural science education is important to determine the direction of research development and opportunities for future study development (Nisa' et al., 2024).

Analysis of the collaborative network of authors and institutions allows for the identification of research centers that have significantly contributed to the development of technology-based multicultural science education (Prada Núñez et al., 2024). This information can serve as a basis for researchers to build broader academic collaborations. Through a bibliometric approach, researchers can obtain a comprehensive overview of research dynamics occurring over a specific period (Elihami & Melbourne, 2022). This analysis not only shows the quantity of publications but also their quality, scientific influence, and interrelationships within a field of study (Munif & Subali, 2025). Therefore, this study is relevant and strategic for analyzing the use of technology in multicultural-based learning. Through a specialized bibliometric analysis, this study aims to address the following research questions:

1. How has research on technology-integrated STEAM education and multicultural science education evolved during the period 2015–2026?
2. What are the dominant research themes, and how do STEAM, technology, science education, and multicultural perspectives relate?
3. What are the emerging themes and research gaps that could provide future research directions?

RESEARCH METHOD

This study used a quantitative descriptive approach integrated with bibliometric analysis. Data were obtained from Scopus-indexed scientific publications spanning 2015–2026. The analysis utilized VOSviewer and Biblioshiny software to map research developments, publication trends, theme developments, and research gaps (Rodriguez, 2021). The bibliographic data collection and filtering process was conducted systematically using Biblioshiny. This study implemented the research method through six systematic stages, as shown in Figure 1.

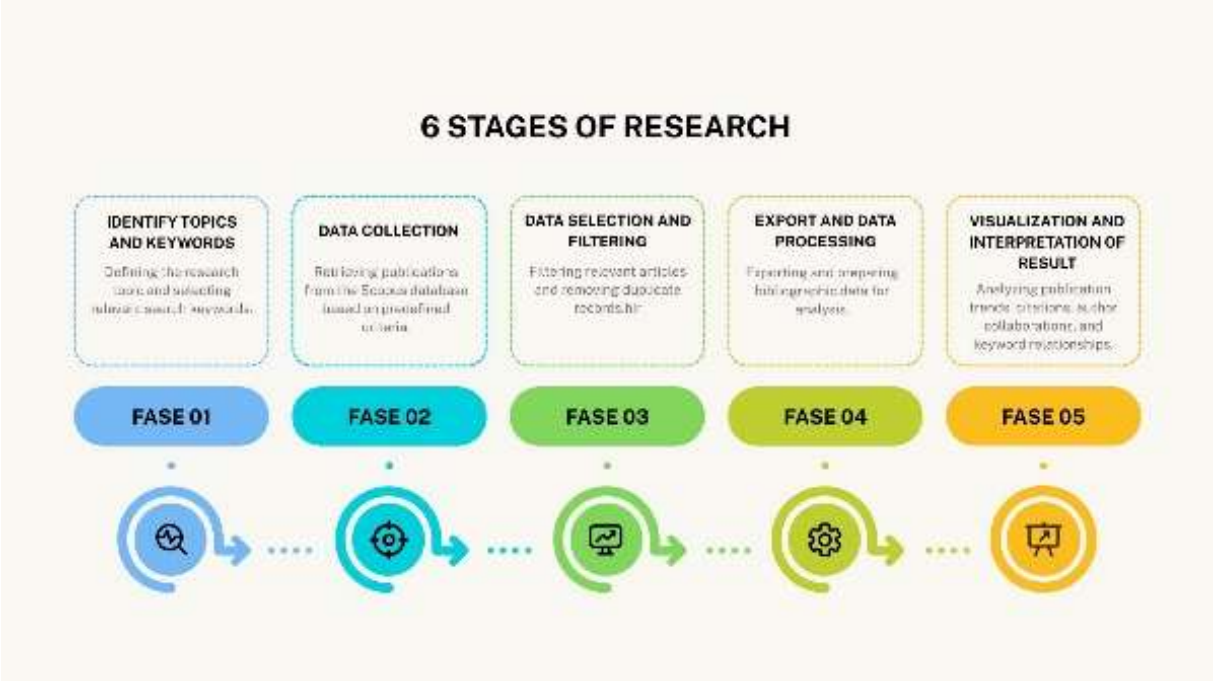


Figure 1. Stage of Research

Figure 1 shows the research stages, which began with determining the research focus, namely technology-supported multicultural science education. The first stage involved determining the research focus, namely technology-supported multicultural science education. The second stage involved data collection by determining the keywords to be used. The third stage involved filtering the data to ensure the quality and relevance of the documents, using a selection process that followed the PRISMA procedure. Data were analyzed using VOSviewer and Biblioshiny software to identify publication trends, keyword relationships, and thematic clusters in the literature (Jackson & Cheng, 2022).

Bibliometric data were obtained from a collection of articles from Scopus. The search was conducted using predetermined keywords, namely ("Education OR Science Education") AND "STEAM") AND ("Culture" OR "Cultural Diversity" OR "Intercultural Education"). The data were filtered for publications from 2015-2026. The data obtained consisted of metadata including article title, author name, abstract, affiliation, source, and number of citations. This stage is crucial for enhancing the validity of the bibliometric analysis results (Choirunnisa et al., 2025). The fourth stage involves processing the obtained data and analyzing it using VOSviewer software. The results are used to address the research objectives. Selected articles are then exported in CSV format. The data is then prepared and analyzed using Biblioshiny and VOSviewer software (Rosyidah et al., 2025). This stage involves checking for data consistency and keyword similarities.

The fifth stage involves analyzing the data using Biblioshiny and VOSviewer. The analysis includes publication trends by year, journal sources, and a scientific network analysis using the co-occurrence of all keywords. This analysis aims to identify research developments, scientific collaborations, and key themes emerging in technology-based multicultural science education. The sixth stage involves visualizing the results as a network map. The visualization results are interpreted to explain research trends, dominant themes, and relationships between concepts.

RESULTS AND DISCUSSION

To gain an overview of the development and direction of research in multicultural science education, a bibliometric analysis of relevant scientific publications was conducted. This analysis aimed to identify patterns of relationships between publication metadata elements. Through this approach, we can understand the distribution of global research attention on science learning issues and the application of multiculturalism in education.

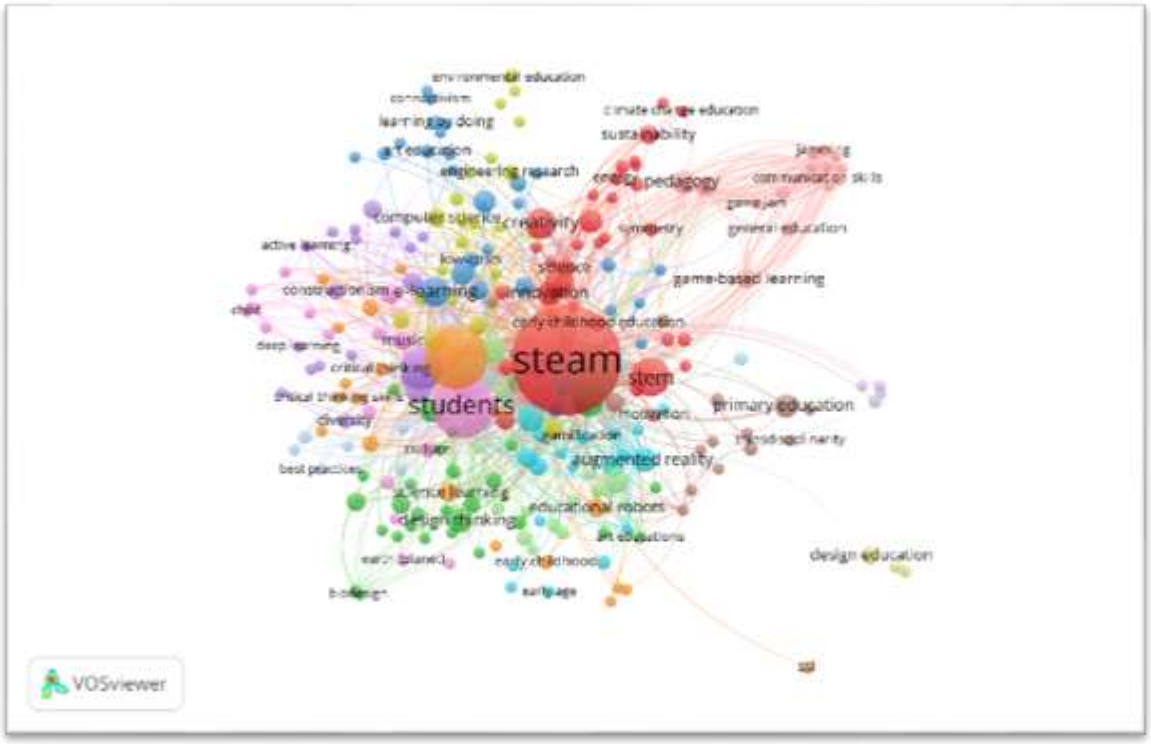


Figure 2. Results of Bibliometric Analysis in VOSviewer

Figure 2 visualizes how research addressing STEAM education has a broader network and is interconnected with various scientific fields. The keyword "STEAM" is the largest node and is located right at the center of the network. This indicates that STEAM is the primary research topic, occurs most frequently among other research topics, and serves as a bridge between various other research topics. Bibliometric analysis shows that larger nodes correspond to more frequent keyword occurrences. Figure 3 shows that the largest node is dominated by the word "STEAM," indicating that STEAM research does not stand alone but rather evolves toward technology-based learning, creativity, and innovation.

The bibliometric analysis using VOSviewer shows color interpretations indicating research groups (clusters). The red cluster focuses on STEAM, containing keywords such as "steam," "creativity," "science," "innovation," "pedagogy," "sustainability," "climate change education," "energy," "game-based learning," "communication skills," and "general education." This cluster shows that STEAM research focuses primarily on learning innovation, creativity, pedagogy, and related areas. This indicates that STEAM research has shifted toward 21st-century competency values through innovative learning. The second color cluster, green, focuses on developing thinking skills and includes the keywords science learning, design thinking, earth, biodesign, and culture. This demonstrates the relationship between STEAM and science thinking, problem solving, design thinking, science learning, and cultural values, indicating that STEAM research is beginning to integrate design thinking skills into science learning.

The third color cluster, blue, focuses on technology and engineering and includes the keywords engineering research, engineering, art education, learning by doing, and connectivism. The blue cluster indicates that STEAM is largely developed through an engineering education approach. Furthermore, the concepts of learning by doing and connectivism emerged, indicating a shift toward technology-based active learning. The fourth color cluster, purple, focuses on digital learning and includes the keywords e-learning, computer science, critical thinking, and active learning. The purple cluster indicates that STEAM research is often combined with e-learning, online learning, computer science, and critical thinking. This demonstrates the interconnectedness between e-learning and STEAM, demonstrating the increased use of digital platforms after the pandemic.

The fifth cluster, orange, focuses on students and contains the keywords "students," "diversity," "music," and "critical thinking skills." STEAM research demonstrates a significant focus on evaluating student learning outcomes, critical thinking skills, student diversity, and arts integration (music). The sixth cluster (immersive technology), containing the keywords "augmented reality," "gamification," "educational robots," and "early childhood," demonstrates the development of modern technology in learning, with

research focusing on augmented reality, educational robots, gamification, and early childhood education. The seventh cluster, brown, contains the keywords "primary education" and "transdisciplinarity," which interpret elementary schools and interdisciplinary learning. The eighth cluster, yellow, contains the keywords "environmental education" and "low-cost," indicating the growth of STEAM research in environmental education and low-cost learning media (low-cost experiments).

In network visualization, more lines indicate a stronger relationship between words. The strongest relationships are shown between words in the concept map below.

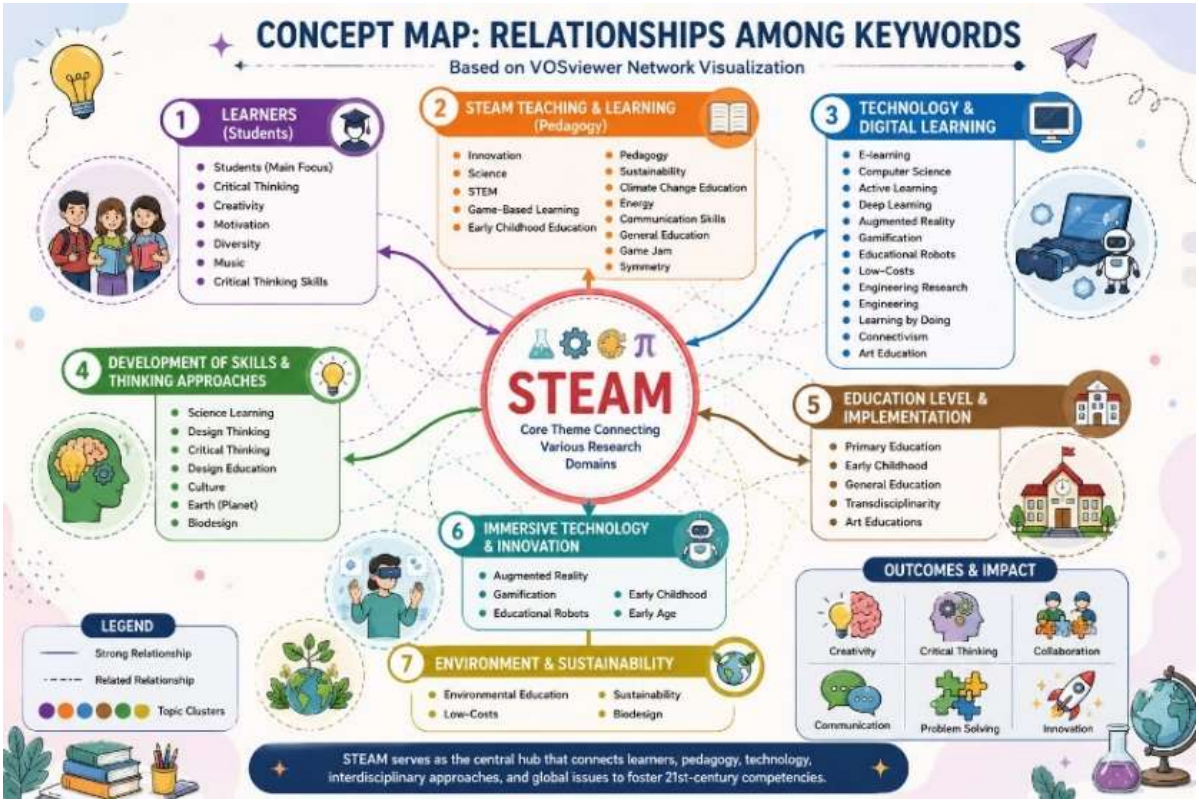


Figure 3. Concept MAP: Relationships Among Keywords

Judging from the node size obtained in the bibliometric analysis, the most dominant keywords are as follows:

Table 1. Analysis Table of the Most Dominant Keywords Appearing

No	Keywords	Interpretation
1	STEAM	Main research topics
2	Students	The main focus of the research object
3	STEAM	The foundation of STEAM development
4	Creativity	The most developed competency
5	Innovation	Innovative learning approach
6	Science	The most dominant subject
7	e-learning	Digital-based learning
8	Game-based learning	Modern learning methods
9	Augmented reality	Developing technology

Figure 3 shows several nodes located on the edge of the network but still connected to the central line. This indicates that these keywords have the potential to become new trends in future research, for example, climate change education, sustainability, environmental education, educational robots, and others. These nodes represent emerging topics, although their frequency is lower than the primary keywords. However, their connection to the word "STEAM" indicates that they have the potential to become a focus for future research.

The network visualization shows a dense network, indicating high collaboration between topics. STEAM research is multidisciplinary and relates not only to science education but also to technology, the arts, the environment, and others. Based on this visualization, it can be concluded that:

STEAM is the center of the research network, with high frequency and connections; STEAM research is predominantly focused on students. The topics most frequently associated with STEAM are creativity, innovation, science, and STEM, confirming that this approach aims to develop 21st-century skills. The increasingly strong integration of digital technology is characterized by keywords such as e-learning, augmented reality, gamification, and educational robots. STEAM is evolving toward global issues through its connection with sustainability, climate change education, and environmental education, thus encompassing not only science learning but also sustainable development. Design thinking and game-based learning approaches are increasingly used methods for implementing STEAM.

Discussion

The results of the bibliometric analysis show that STEAM is the most dominant theme in the technology-based multicultural science education research landscape. STEAM's position as a network hub indicates that this approach has developed into a major framework that integrates science, technology, engineering, arts, and mathematics in contextual learning and is oriented towards solving real problems. This dominance shows that the current development of science education no longer only focuses on mastering scientific concepts, but also on creative, collaborative, communicative, and problem-solving thinking skills, which are the main competencies of the 21st century. This finding aligns with constructivist learning theory, which states that knowledge is built through learning experiences that are meaningful, collaborative, and related to students' lives. From a multicultural education perspective, STEAM integration also supports the idea that science learning should respect cultural diversity as a learning resource that can increase the relevance and meaningfulness of learning.

Network analysis also shows that the keywords creativity, innovation, science, and students have a very strong relationship with STEAM. This shows that current research is more oriented towards developing student competencies rather than simply delivering learning material. This connection supports the 21st Century Skills framework, which places creativity, critical thinking, collaboration, and communication as main competencies in modern education. Thus, technology-based multicultural science education not only functions as a medium for knowledge transfer but also as a means of building students' adaptive abilities to face the challenges of an increasingly complex and diverse global society.

Another interesting finding is the emergence of e-learning, game-based learning, augmented reality, educational robots, and design thinking as keywords closely related to STEAM. This phenomenon shows a transformation of the learning paradigm from conventional learning to digital learning, which is more interactive, flexible, and student-centered. This development can be explained through Connectivism theory, which states that learning in the digital era occurs through technological networks and extensive information exchange. Technology no longer functions only as a learning tool; it has become a learning environment that allows students to build knowledge through interaction, exploration, and collaboration. Therefore, the results of this research strengthen the idea that technology integration is an inseparable element in developing multicultural science education in the digital era.

The results also show that several topics, such as climate change education, environmental education, sustainability, and educational robots, remain on the periphery of the network even though they relate to the main theme. This condition shows that these topics are still at the emerging research topics stage, namely fields of study that are starting to develop but have not yet become the main focus of research. From the perspective of the diffusion of innovation theory, this phenomenon shows that innovation in science education develops gradually through an adoption process before finally becoming mainstream research. Thus, opportunities for research development remain broad, especially in integrating sustainability issues, smart technology, and multicultural education into science learning.

Compared with previous bibliometric research, this study's results are similar in showing an increase in publications on integrating technology in science education, as well as growing attention to the STEAM approach. However, this research makes a more specific contribution by mapping the relationship between STEAM, digital technology, and multicultural perspectives in one analytical network. Most previous research discusses the development of STEAM or educational technology separately, while the results of this research show that these three aspects develop in an integrated manner.

Based on the first research question, the analysis shows that research on technology-integrated STEAM education and multicultural science education is progressing toward learning that is more interdisciplinary, contextual, and supported by digital technology. This is evident in STEAM's position as a central theme in the research network and its connections to science, creativity, innovation, e-learning, game-based learning, augmented reality, and design thinking. These findings indicate that STEAM research development is no

longer only oriented toward integrating several scientific disciplines, but also toward using technology and developing student competencies. These results align with research on the development of STEAM in science learning, which shows that STEAM is increasingly studied as an approach to developing 21st-century skills and interdisciplinary learning.

Based on the second research question, the most dominant themes in the research network are STEAM, students, creativity, innovation, science, e-learning, game-based learning, and augmented reality. The strong relationships between themes show that STEAM research is increasingly linked to the use of digital technology and the development of students' abilities. Technology integration functions not only as a tool to deliver material, but also as a learning environment that allows students to explore, interact, collaborate, and solve problems. This finding is strengthened by a systematic study showing that STEAM is closely related to digital competence and sustainable innovation. In addition, bibliometric studies on digital technology in science education show that research in this area continues to develop and involves various forms of learning technology. The connection between STEAM and culture demonstrates that cultural context can be a crucial aspect in developing more meaningful science education. Instruction that integrates cultural contexts or local assets links scientific concepts to learners' real-life experiences. Consequently, a multicultural perspective is not merely an add-on to the curriculum but can reinforce the relevance of science learning.

Based on the third research question, the network visualization results show that several themes, such as climate change education, environmental education, sustainability, educational robots, and local cultural integration, remain in the peripheral part of the network. This position shows that these themes are not yet dominant, but they relate to the main theme and have the potential to become directions for future research. This finding is in line with the development of STEAM research, which increasingly links this approach to issues of sustainability and digital competence. The latest bibliometric research on STEAM and SDGs also shows the development of research linking STEAM with sustainable development issues.

Thus, the three research questions can be answered by noting that STEAM education research is evolving toward the integration of STEAM, digital technology, learner competency development, and cultural contexts. Meanwhile, sustainability, environmental education, educational robotics, and the integration of local culture represent areas that offer further opportunities for development. These findings indicate that future research should not merely focus on developing STEAM technologies or approaches in isolation; rather, it should examine how digital technology, STEAM, cultural contexts, and sustainability issues can be integrated into contextual and inclusive science learning.

These findings expand understanding regarding the direction of development of contemporary science education, which is not only oriented towards technological innovation, but also towards strengthening cultural diversity and global competence of students. Based on the overall analysis results, this research proposes a conceptual perspective that the development of science education in the 21st century is moving towards a learning model that integrates STEAM, digital technology, and multicultural education as three complementary pillars. The integration of these three components makes it possible.

CONCLUSION

The research demonstrates that the research landscape of technology-enabled multicultural science education is becoming increasingly dynamic and multidisciplinary. Bibliometric analysis using Biblioshiny and VOSviewer identified STEAM as a central theme with the strongest connections to various research topics, such as creativity, innovation, science learning, design thinking, e-learning, game-based learning, and augmented reality. These findings indicate that science education is no longer solely focused on mastering scientific concepts, but has shifted toward learning that integrates technology, strengthens 21st-century competencies, and incorporates diversity values into the learning process.

The implications of this research confirm that bibliometric mapping can provide a comprehensive overview of the direction of scientific development and serve as a basis for formulating future research and learning development strategies. Integrating technology with a STEAM approach and a multicultural perspective has the potential to create science learning that is more contextual, inclusive, innovative, and relevant to global challenges. Furthermore, the results of this study can serve as a reference for researchers, educators, and policymakers in developing learning models that accommodate cultural diversity while optimally utilizing advances in digital technology.

However, the analysis also shows that themes such as climate change education, environmental education, educational robots, sustainability, and local cultural integration still occur relatively infrequently, opening opportunities for further research. Therefore, future research should expand the study

of implementing technology-based multicultural science education in various cultural contexts, strengthen cross-national and cross-disciplinary collaboration, and explore the use of more advanced digital technologies to support sustainable learning. Thus, research in this area is expected not only to map the development of science but also to contribute significantly to transforming science education to be inclusive, adaptive, and oriented to the needs of the global community.

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