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Knowledge Network Mapping in Education and Technology Research: A Bibliometric Analysis

Muhammad Awaluddin[1*], Ika Safitri Windiarti[2]

[1]Doctoral Program of Universiti Muhammadiyah Malaysia, Malaysia
[2]Doctoral Program of Universiti Muhammadiyah Malaysia and Universitas Muhammadiyah Palangkaraya, Malaysia, Indonesia

ABSTRACT

The rapid development of technology has significantly transformed the field of education, leading to an increasing number of studies on the integration of technology in learning processes. However, the growing volume of publications presents challenges in identifying research trends, thematic structures, and collaboration patterns. This study aims to map the knowledge network in education and technology research using a bibliometric approach. This research employs a quantitative bibliometric method by analyzing scientific publications obtained from reputable databases. Data were collected based on relevant keywords and processed using techniques such as co-authorship, co-occurrence, citation, and co-citation analysis. Visualization tools, including VOSviewer, were used to identify research clusters and network relationships. The results reveal a significant increase in publications, with dominant topics including digital learning, artificial intelligence in education, and online learning. Cluster mapping shows interconnected themes such as learning technology, pedagogical innovation, digital literacy, and technology-based evaluation. In addition, collaboration patterns are still largely institution-based, although international cooperation has increased. In conclusion, education and technology research continues to evolve toward intelligent technology integration, personalized learning, and the development of 21st-century skills. These findings provide valuable insights for future research directions and strategic academic development.

Keywords: *Bibliometric Analysis; Education Technology; Knowledge Network; Research Trends*

1. Introduction

The rapid advancement of science and technology over the past few decades has driven significant transformations in the field of education. The integration of technology into the learning process has not only altered methods of content delivery but also expanded the scope of research in education and technology (Capolupo, 2024). Various innovations, such as digital-based learning, artificial intelligence, and online learning platforms, have become central focuses in academic studies, resulting in a substantial increase in scientific publications. The abundance of these publications presents a particular challenge for researchers, namely the difficulty in identifying the direction of research development, major trends, and the relationships among emerging

Korespondensi: Muhammad Awaluddin, Email: p5240042@student.umam.edu.my

topics (İnci, 2024). In this context, an approach is required that can systematically and comprehensively map the structure of knowledge. One relevant method is bibliometric analysis, which enables researchers to explore publication patterns, scientific collaboration, and the interconnections among concepts within a specific field of study.

Knowledge network mapping has become an essential technique in bibliometric analysis, functioning to visualize the relationships among researchers, institutions, and keywords within a particular field of study. Through this mapping, research clusters, dominant topics, and opportunities for future research development can be identified (Selamoglu, 2024). In the field of education and technology, knowledge network mapping is increasingly important due to its multidisciplinary and dynamic nature. To date, there remain limitations in studies that specifically and comprehensively map knowledge networks in education and technology research (Mota et al., 2024). Many studies tend to focus on descriptive analysis without deeply examining the relational structures among elements of knowledge. This has resulted in a less optimal understanding of the direction of the field's development as well as the potential for collaboration that could be further explored (Mariappan et al., 2024).

Although research in the field of education and technology continues to grow rapidly, there remains a significant gap in the comprehensive and integrated mapping of knowledge structures, particularly in identifying relationships among topics, collaboration patterns, and the systematic direction of research development (Ashiq et al., 2021). Many previous studies have been partial and predominantly descriptive in nature, and thus have not been able to provide a holistic picture of the dynamics of knowledge networks (Rahman et al., 2023). The challenges faced include the continuously increasing volume of publications, the diversity of disciplines involved, and the limited utilization of advanced bibliometric methods and analytical tools (Z. Li et al., 2024). In addition, differences in databases, variations in metadata quality, and restricted access to scientific sources also hinder the production of accurate and representative mappings (Sreenivasan et al., 2023). These conditions call for a more systematic, technology-based analytical approach capable of integrating multiple data sources to generate a deeper understanding of research developments in the field of education and technology.

A number of previous studies have employed bibliometric analysis to map research developments in the field of education and technology. For instance, (P. Li et al., 2022) emphasize that bibliometric methods are effective in identifying research trends and the intellectual structure of a field. Furthermore, (X. Wang et al., 2024) introduced the use of VOSviewer for knowledge network visualization, which is capable of revealing topic clusters and relationships among researchers. Research by (Setianingrum & Costa, 2023) also highlights the importance of techniques such as co-citation and co-word analysis in understanding the structure of scientific literature. On the other hand, (Vanhulst & Beling, 2021) developed a visualization approach through CiteSpace, which assists in identifying trends and emerging topics within a discipline. Meanwhile, (Yuliani et al., 2022) demonstrates that technology-based education research has experienced significant growth; however, it still requires more in-depth mapping to uncover interrelationships among topics. These findings indicate that although bibliometric analysis has been widely applied, more comprehensive

studies are still needed to systematically and integratively map knowledge networks in the field of education and technology.

Based on these conditions, this study is important to conduct in order to analyze and map knowledge networks in the field of education and technology through a bibliometric approach. This approach enables the identification of relational patterns among topics, authors, and institutions in a more systematic and data-driven manner. Therefore, this research not only serves as a mapping effort but also as a means to gain a more comprehensive understanding of the dynamics of scientific development. The findings of this study are expected to provide a clear overview of research trends, the structure of scientific collaboration, and the future directions of research development. In addition, the results are anticipated to serve as a strategic reference for academics, researchers, and practitioners in designing studies that are more focused, innovative, and relevant to contemporary developments, particularly in the integration of education and technology.

2. Methods

This study employs a quantitative research design with a bibliometric approach aimed at analyzing and mapping the development of knowledge in the field of education and technology. The study utilizes secondary data in the form of scientific publications obtained from reputable databases, which are then analyzed using descriptive statistical techniques and network visualization to identify relational patterns among authors, keywords, and publication sources (Moshiul et al., 2022). Through this approach, the research focuses on uncovering research trends, the structure of scientific collaboration, and emerging topic clusters, thereby providing a systematic and comprehensive overview of knowledge networks within the field under investigation.

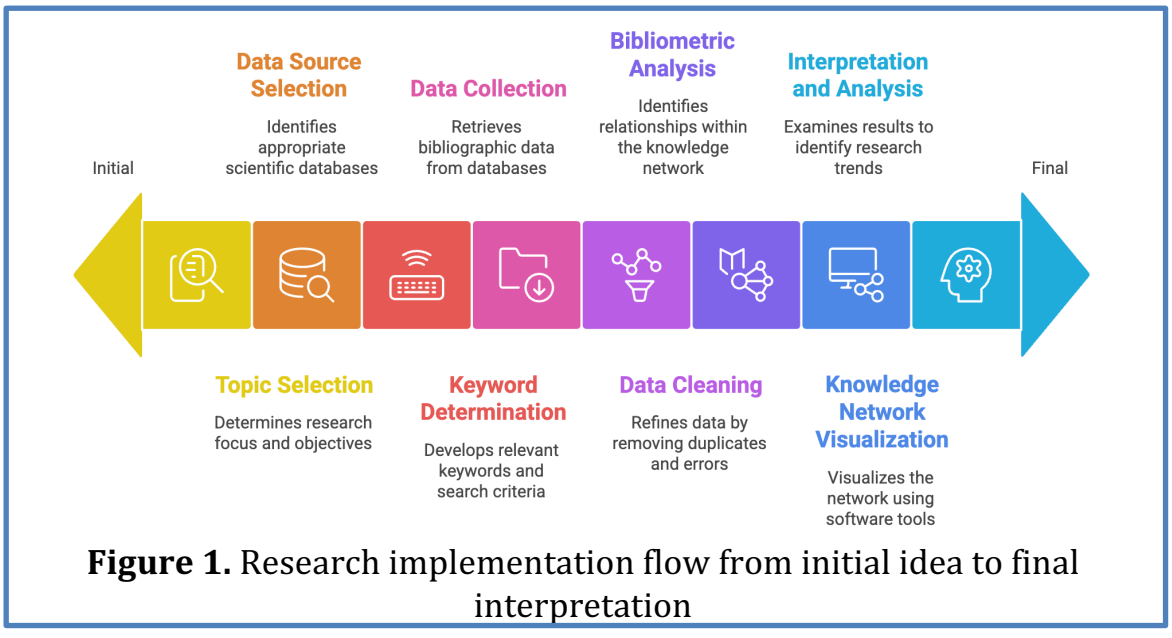

Figure 1. Research implementation flow from initial idea to final interpretation

Data collection in this study was conducted by utilizing reputable scientific databases, such as Scopus, Web of Science, and Google Scholar, which provide relevant publications in the field of education and technology (Lubis & Yus, 2024). The researcher first identified appropriate keywords, such as "education," "technology," and "educational technology," and then

developed a search strategy by considering Boolean operators (AND, OR) as well as inclusion and exclusion criteria, including publication year range, document type (journal articles, conference proceedings), and language (Kataria, 2025). This process aimed to obtain data that are relevant and aligned with the research focus. Subsequently, the bibliographic data obtained were downloaded in specific formats, such as CSV, RIS, or BibTeX, containing essential information including titles, authors' names, abstracts, keywords, publication years, and reference lists (J. Wang et al., 2025). The data were then compiled and refined to eliminate duplicates and ensure consistency, particularly in the standardization of author names and keyword terms. This stage is crucial to ensure data quality before proceeding to further analysis.

Data analysis in this study employs a bibliometric approach by utilizing techniques such as co-authorship, co-occurrence (keywords), citation, and co-citation. These techniques are used to identify patterns of relationships among authors, the interconnections among concepts, and the level of influence of a publication within the scientific network (Ying & Mohamad, 2025). The analysis is conducted with the assistance of specialized software such as VOSviewer and CiteSpace, which are capable of processing large volumes of data and generating systematic network visualizations. The results of the analysis are then presented in the form of network visualization maps, illustrating research clusters, dominant topics, and patterns of scientific collaboration (Ye et al., 2025). Subsequently, the researcher interprets these visualizations to uncover research trends, the evolution of topics over time, and potential areas for future investigation. Thus, the data analysis not only provides a descriptive overview but also offers deeper insights into the structure and dynamics of research in the field of education and technology.

3. Findings and Discussion

3.1 Findings

The results of this study were obtained through a series of bibliometric analyses involving the mapping of knowledge networks based on scientific publication data in the field of education and technology. The analysis process was conducted using techniques such as co-authorship, co-occurrence, citation, and co-citation, which aim to identify relational patterns among research elements. Through this approach, the researcher was able to reveal the intellectual structure, the dynamics of topic development, and the interconnections among concepts within the field under study. The resulting knowledge network visualizations provide a comprehensive overview of research clusters, major trends, and patterns of scientific collaboration. The interpretation of these visualizations enables a deeper understanding of the direction of research development, including the identification of dominant topics as well as those that still offer opportunities for further exploration. Based on the results

of this analysis, several key findings were identified and are summarized in the following points:

Identification of Research Trends

The identification of research trends in the field of education and technology indicates a very rapid development in recent years. Based on the results of bibliometric analysis, the number of scientific publications has increased significantly, reflecting the high level of academic interest in the integration of technology into education. This growth not only represents an increase in the quantity of research but also demonstrates an expansion in the scope of studies, which has become more complex and multidisciplinary. One of the main trends identified is the growing focus on digital learning as a form of transformation in modern education. Digital learning enables teaching and learning processes to occur flexibly, without limitations of space and time, and is supported by various technological platforms. This trend has become increasingly relevant in response to the need for adaptive educational systems that align with technological advancements and social changes.

The topic of artificial intelligence in education also shows substantial growth. The emergence of these technologies serves as a key indicator in the evolution of educational systems toward a more intelligent and data-driven paradigm. On the other hand, online learning remains one of the dominant topics in research, particularly following the increased demand for distance education. This model encourages the development of innovative methods, strategies, and learning media to maintain the quality of education in virtual environments. Overall, these three major focuses indicate that the direction of research in education and technology is increasingly oriented toward the utilization of digital technologies to create more effective, efficient, and sustainable learning systems.

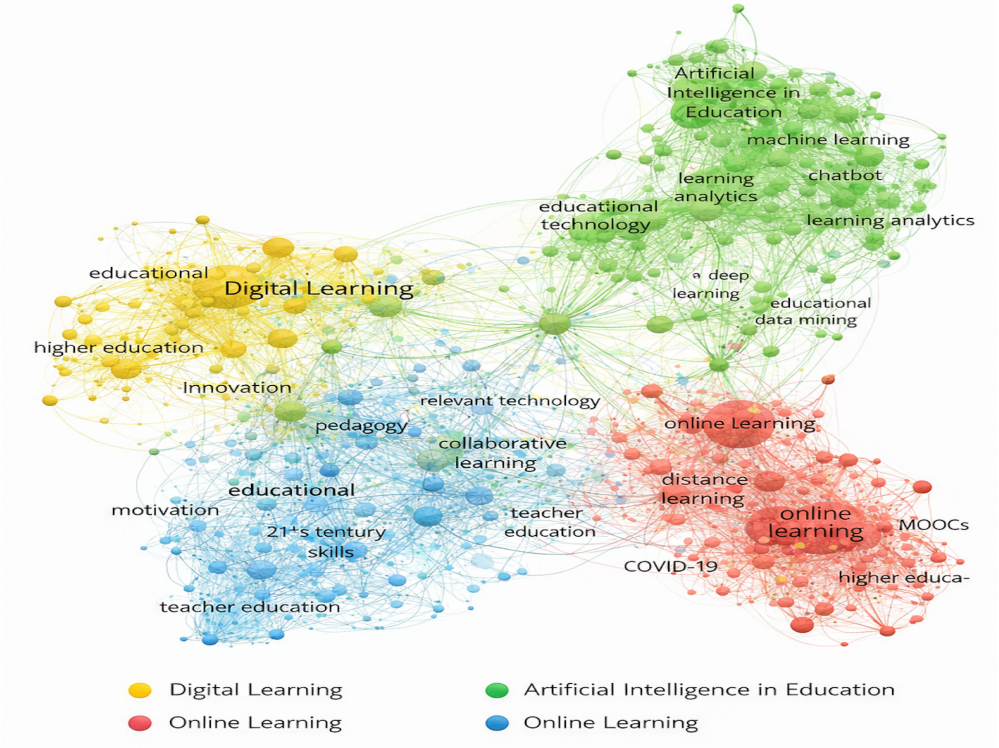

Figure 2. Trends in Education and Technology

The figure presents a visualization of the knowledge network in the field of education and technology, generated through bibliometric analysis using tools such as VOSviewer. Each node (point) in the map represents a keyword or research topic, while the connecting lines indicate relationships or linkages among topics. The size of each node reflects the frequency of occurrence or the dominance of a topic, whereas the colors represent clusters that group related research themes.

On the left side of the figure, the yellow cluster is dominated by the topic of digital learning. This cluster is closely associated with concepts such as higher education, innovation, and the development of learning technologies. This indicates that digital learning serves as a fundamental pillar in modern educational research, particularly in the context of transforming learning methods to be more flexible and technology-based. In the upper-right section, the green cluster illustrates a research focus on artificial intelligence in education. Topics such as machine learning, learning analytics, and chatbots suggest that the application of artificial intelligence is increasingly advancing to support learning processes. This cluster reflects a shift toward more adaptive, personalized, and data-driven educational systems. Meanwhile, the red cluster in the lower-right section highlights the dominance of online learning, closely related to distance learning, MOOCs, and global situations such as COVID-19. On the other hand, the blue cluster represents pedagogical aspects, including teacher education, 21st-century skills, and learning motivation. Overall, this visualization demonstrates that research in education and technology is multidimensional in nature, characterized by strong interconnections among digital technologies, learning innovation, and the development of educational competencies in the modern era.

Mapping of Research Topic Clusters

The mapping of research topic clusters indicates that the field of education and technology is composed of several major thematic groups that are interconnected. Based on the results of network visualization, distinct clusters can be identified representing learning technologies, pedagogical innovation, digital literacy, and technology-based learning evaluation. Each cluster reflects a specific research focus that has developed within the scientific community, while maintaining strong interconnections through conceptual relationships and research collaboration. These inter-cluster linkages demonstrate that research development does not occur in isolation but rather evolves in a complementary manner, forming a dynamic scientific ecosystem. For instance, pedagogical innovation is often supported by the use of learning technologies, while digital literacy serves as a crucial prerequisite for the implementation and evaluation of technology-based learning. Therefore, this cluster mapping provides a comprehensive overview of the research structure and helps identify both well-developed areas and potential directions for future research.

The mapping of research topic clusters in this study was conducted through co-occurrence analysis of keywords, which was visualized in the form of a knowledge network using VOSviewer. Each cluster formed represents a group of research themes that share strong relationships based on their frequency of co-occurrence in scientific publications. Through this approach, the researcher is able to systematically and data-drivenly identify the conceptual structure of the field of education and technology. The visualization not only highlights the

grouping of topics but also reveals the interconnections among clusters. This indicates that research in education and technology is inherently multidisciplinary and mutually reinforcing. To provide a more structured overview, the results of the cluster mapping are presented in the following table.

Table 1. Mapping of Research Topic Clusters Based on Network Visualization

Cluster Name	Main Topics / Keywords	Description
Learning Technology	Digital Learning, Educational Technology, M-learning	Focuses on the use of technology in digital learning processes and innovation in learning media.
Artificial Intelligence in Education	Machine Learning, Learning Analytics, Chatbot	Examines the application of artificial intelligence for personalization and learning analytics.
Pedagogical Innovation	Pedagogy, Innovation, Teacher Education	Emphasizes the development of innovative teaching methods and strategies.
Digital Literacy	Communication, Relevant Technology	Relates to digital literacy skills in supporting technology-based learning.
Technology-Based Learning Evaluation	Assessment, Evaluation, Learning Outcomes	Focuses on evaluating the effectiveness of technology-based learning.
Online Learning	Distance Learning, MOOCs, COVID-19	Examines online learning and its implementation in various educational contexts.

The Learning Technology cluster highlights the critical role of technology as a foundational element in the transformation of modern learning. Topics such as digital learning and educational technology indicate that technology is not merely a supporting tool but an integral component of innovative and adaptive instructional design. Meanwhile, the Artificial Intelligence in Education cluster reflects significant advancements in integrating artificial intelligence into learning processes. The presence of topics such as machine learning and learning analytics suggests a shift toward data-driven educational approaches that enable personalized learning and enhance evaluation effectiveness.

The pedagogical Innovation cluster emphasizes the importance of developing creative and contextual teaching strategies. This cluster is closely associated with improving educators' competencies, particularly in designing instruction that meets the demands of 21st-century skills. On the other hand, the Digital Literacy cluster underlines the importance of individuals' ability to effectively utilize technology, which serves as a prerequisite for implementing digital-based learning. Finally, the Technology-Based Learning Evaluation and Online Learning clusters highlight a focus on evaluation and implementation within digital learning environments. Technology-based evaluation plays a crucial role in measuring learning effectiveness, while online learning reflects the adaptation of educational systems to global changes. These clusters indicate that the successful integration of technology in education depends not only on innovation but also on the effectiveness of its implementation and evaluation.

Scientific Collaboration Patterns

Scientific collaboration patterns in this study were analyzed using a co-authorship approach, which illustrates how collaborative relationships among researchers are formed within a particular field of study. The results indicate that collaboration tends to be concentrated within specific institutions or countries, where researchers more frequently collaborate with colleagues within the same academic environment or geographical proximity. This pattern is influenced by factors such as shared affiliations, ease of communication, and the existence of previously established research networks. However, in recent years, there has been a notable increase in international collaboration. Advances in communication technology and improved access to scientific information have created greater opportunities for researchers from different countries to collaborate on broader research projects. Such cross-national collaboration not only enriches scientific perspectives but also enhances the quality and impact of research, thereby accelerating the global development of the education and technology field.

The analysis of publication distribution by country was conducted to identify geographical contributions to research development in education and technology. This approach is essential for understanding which countries play dominant roles in knowledge production and how research is distributed globally. By utilizing bibliometric data, researchers can observe patterns of scientific productivity that reflect research capacity, institutional support, and levels of international collaboration. The findings are presented through a horizontal bar chart visualization, allowing for clearer and more comparative data representation. This type of visualization enables readers to easily compare the number of publications across countries and to identify differences in contributions based on specific categories represented by distinct colors. Such presentation facilitates the identification of countries with the highest contributions as well as those that are still developing in this research domain.

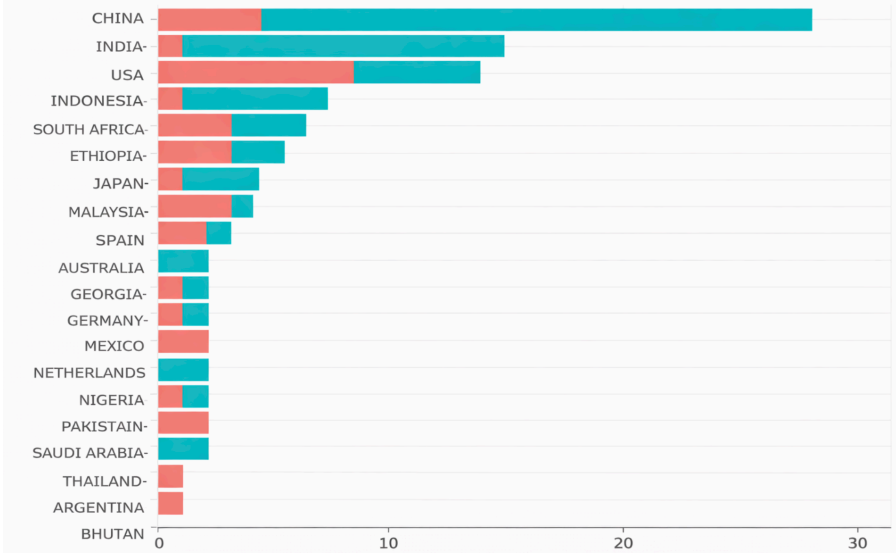

Figure 3. Scientific Collaboration Pattern Graph

Based on the graph, China appears as the leading country with the highest number of publications, followed by India and the United States. The dominance

of these countries reflects strong investment in research and development, as well as high academic productivity in the field of education and technology. Indonesia also demonstrates a relatively significant contribution, indicating increasing research activity in the Southeast Asian region. In addition, countries such as South Africa, Ethiopia, and Japan show relatively stable contributions, although not as prominent as the leading countries. This suggests a more even distribution of research growth across different regions, including developing countries that are becoming increasingly active in producing scientific publications. This condition reflects the growing accessibility of research resources on a global scale.

The variation in colors within the graph indicates the presence of categorized data, which may represent different time periods or types of contributions. This distinction provides additional insights into publication dynamics, such as increases in research output over certain periods or differences in the types of publications produced by each country. Therefore, the graph not only presents quantitative data but also offers contextual understanding of research development. Overall, the graph demonstrates that research contributions in the field of education and technology are still dominated by a few countries, yet exhibit a positive growth trend globally. These findings have important implications for research policy development, particularly in promoting international collaboration and ensuring a more equitable distribution of research quality across countries.

Impact and Citation of Publications

The analysis of publication impact and citation in this study was conducted using citation and co-citation approaches, which aim to identify scientific works and authors that have made significant contributions to the development of the field of education and technology. Through this analysis, it is possible to determine which publications are most frequently cited by other researchers, thereby reflecting the level of influence and relevance of a work within the academic community. The higher the number of citations, the greater the role of the publication in shaping subsequent research directions.

The results reveal that several key articles and authors serve as central references within the knowledge network. These influential publications generally address fundamental concepts, technological innovations in education, and methodological approaches that are widely adopted by other researchers. The presence of such highly cited works forms a strong theoretical foundation and serves as a primary reference in advancing research in education and technology. Co-citation analysis further uncovers relationships among publications that are frequently cited together. This pattern indicates that these works share similar topics or offer complementary contributions in explaining particular research phenomena. Thus, co-citation analysis not only identifies influential publications but also helps map the intellectual structure and conceptual relationships within a field of study. Overall, these findings highlight the crucial role of highly cited publications in shaping the direction and development of research. Influential articles and authors function not only as key references but also as drivers of innovation in education and technology. Therefore, understanding citation patterns is essential for researchers in identifying key literature and designing studies that are both relevant and impactful.

The citation and co-citation analyses in this study are visualized in the form of a network map using tools such as VOSviewer. In this visualization, each node represents an article or author, while the connecting lines indicate citation relationships among publications. The size of each node reflects the level of influence based on the number of citations, and the colors represent clusters grouped according to topical similarity. This network-based visualization facilitates a clearer understanding of the intellectual structure of the field. Through this map, researchers can directly observe the interconnections among scientific works and identify key knowledge hubs that serve as major references in the development of theory and practice in technology-based education. Therefore, this visualization serves as an effective tool for comprehensively exploring the dynamics and evolution of research.

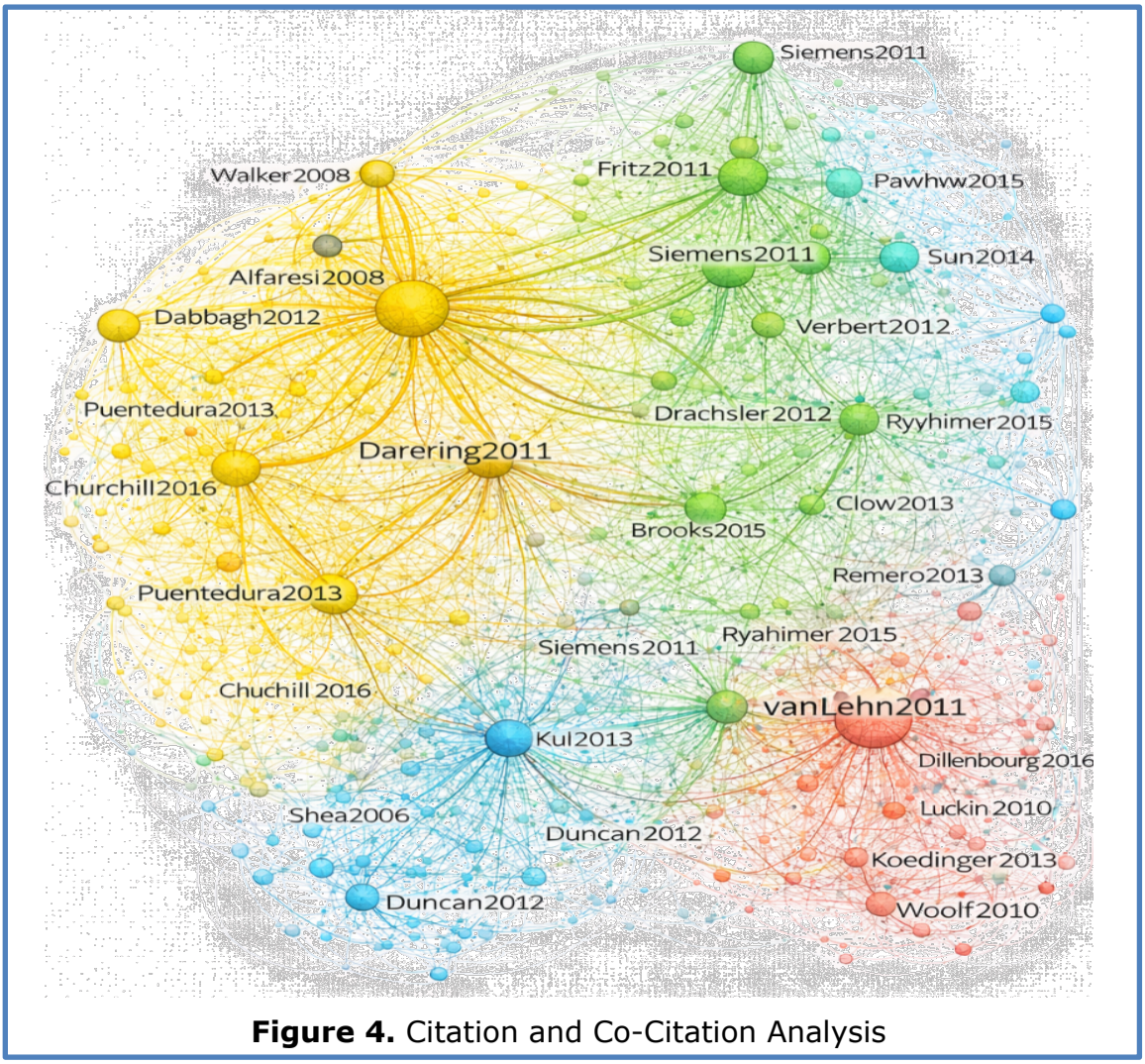

Figure 4. Citation and Co-Citation Analysis

Based on the figure, several major clusters can be observed, grouping publications according to topical similarity and the strength of their citation relationships. These clusters indicate that research in the field of education and technology develops across multiple interconnected areas of focus. Each cluster contains dominant nodes with larger sizes, representing publications or authors that exert significant influence within the network. Moreover, the dense connections among nodes reflect a high level of interrelatedness among publications. This suggests that research in this field is complementary in nature, where one scientific work serves as a foundation or reference for others. Such a

pattern demonstrates continuity in the development of knowledge and highlights that highly cited research tends to become a central focus within the academic community.

The different colors assigned to each cluster further indicate the grouping of specific research themes. For instance, certain clusters focus on learning technologies, pedagogical innovation, and the integration of artificial intelligence in education. These color distinctions facilitate the identification of the conceptual structure and the direction of research development within the field. Overall, this visualization reveals that several key publications play a crucial role in shaping the direction of research in education and technology. These works function as primary references and exert substantial influence on subsequent studies. Therefore, citation and co-citation analyses not only assist in identifying important literature but also provide deeper insights into the structure and dynamics of knowledge development within the field.

Future Research Directions and Opportunities

Future research directions and opportunities in the field of education and technology can be identified based on development patterns and clusters revealed through bibliometric analysis. The findings indicate that future studies will increasingly focus on the integration of intelligent technologies into learning processes. Technologies such as artificial intelligence, machine learning, and learning analytics are predicted to play a crucial role in creating more adaptive, responsive, and data-driven educational systems. In addition, personalized learning emerges as a key focus with significant potential for further development. This approach enables learning processes to be tailored to the needs, abilities, and learning styles of individual learners. With the support of digital technologies, personalization not only enhances learning effectiveness but also provides more meaningful, learner-centered experiences.

The strengthening of 21st-century skills also represents an important focus in future research directions. Skills such as critical thinking, creativity, collaboration, and digital literacy are essential competencies that learners must possess to face global challenges. Therefore, research in education and technology is expected to develop learning models that are not only technology-based but also oriented toward the cultivation of these competencies. Overall, future research opportunities are widely open due to the rapid advancement of technology. The integration of intelligent technologies, personalized learning approaches, and the reinforcement of 21st-century skills indicates that research in this field will continue to evolve dynamically. This creates ample opportunities for researchers to explore new innovations that can enhance the quality of education and ensure its relevance to contemporary societal needs.

Table 2. Future Research Directions Based on VOSviewer Clusters

Cluster Name	Key Topics / Keywords	Research Direction	Future Opportunities
Intelligent Technology Integration	Artificial Intelligence, Machine Learning, Analytics	Integration of intelligent technologies in learning	Development of adaptive and data-driven learning systems

Personalized Learning	Adaptive Learning, Learning Style, Student-Centered	Personalization of the learning process	Design of learning systems tailored to individual learners' needs
Digital Learning Environment	E-learning, Online Learning, Digital Platforms	Strengthening digital learning ecosystems	Innovation in interactive and flexible learning platforms
21st Century Skills Development	Critical Thinking, Creativity, Collaboration	Development of 21st-century skills	Integration of soft skills into technology-based curricula
Learning Analytics and Evaluation	Assessment, Data Analysis, Learning Outcomes	Technology-based learning evaluation	Development of real-time data-driven evaluation systems
Educational Innovation	Pedagogical Innovation, Instructional Design	Innovation in teaching methods and strategies	Development of more effective hybrid and technology-based learning models

The mapping of future research directions and opportunities was conducted by analyzing the clusters generated from VOSviewer visualizations. Each cluster represents a research theme with strong interconnections and reflects the developmental tendencies within the field of education and technology. Through this approach, researchers are able to identify not only currently dominant research areas but also those with strong potential for future development. The results of this mapping are then organized into a table to provide a more systematic and structured overview of research directions. The table includes information on cluster names, key topics, research directions, and potential opportunities, serving as a useful reference for future researchers. Thus, presenting the findings in tabular form facilitates a clearer and more comprehensive understanding of research focus and potential.

Based on the table, the *Intelligent Technology Integration* cluster indicates that the use of advanced technologies such as artificial intelligence and machine learning will become a primary focus of future research. The development of adaptive learning systems capable of automatically adjusting to users' needs presents significant opportunities to enhance learning effectiveness. This trend reflects a shift toward data-driven and technologically advanced education. Furthermore, the *Personalized Learning* and *Digital Learning Environment* clusters emphasize the importance of learner-centered approaches supported by flexible digital environments. Personalized learning enables individuals to experience instruction tailored to their unique characteristics, while the strengthening of digital ecosystems promotes broader and more inclusive access to education.

The *21st Century Skills Development* and *Educational Innovation* clusters demonstrate that research is not solely focused on technology but also on competency development and instructional methods. The integration of essential

skills such as critical thinking, creativity, and collaboration is crucial in addressing global challenges. This is further supported by ongoing pedagogical innovations aimed at improving the quality of learning. Finally, the *Learning Analytics and Evaluation* cluster highlights the importance of data-driven evaluation in ensuring the effectiveness of educational processes. The use of learning analytics enables real-time performance monitoring and more accurate decision-making. Overall, the table illustrates that future research directions will increasingly integrate technology, pedagogy, and competency development, thereby opening broad opportunities for innovation in the field of education and technology.

3.2 Discussion

The discussion on the identification of research trends indicates that the increasing number of publications in the field of education and technology serves as a strong indicator of the growing academic interest in the integration of technology into learning processes. This phenomenon is closely linked to the rapid advancement of digital technologies, which has driven transformations across various aspects of education. These findings are consistent with global trends showing that research in this field is evolving dynamically and has become a major focus within multidisciplinary studies. The emphasis on digital learning highlights a shift from conventional teaching methods toward technology-based approaches. Digital learning enables greater flexibility in accessing materials, facilitating interaction, and conducting assessments, making it a relevant solution to contemporary educational challenges. This development is further supported by the increasing use of digital devices and online learning platforms, which expand learning opportunities for students beyond traditional classroom boundaries.

The growing attention to artificial intelligence in education suggests that technology is not only used as a medium but also as a powerful tool to significantly enhance the quality of learning. The application of artificial intelligence enables in-depth analysis of learning data, supporting more accurate and informed decision-making in educational processes. This reflects a transition toward more adaptive and personalized learning systems. Meanwhile, the prominence of online learning reinforces the importance of distance education as an integral part of modern educational systems. Global circumstances that necessitate remote learning have accelerated the adoption of educational technologies (Aziz et al., 2024). Overall, these three major trends demonstrate that research in education and technology is increasingly oriented toward digital innovation. This orientation not only improves the efficiency of learning processes but also opens new opportunities for developing more inclusive and sustainable educational systems.

The discussion on the mapping of research topic clusters reveals that the field of education and technology possesses a complex and interconnected intellectual structure. The analysis identifies several major clusters representing evolving research themes, such as learning technologies, pedagogical innovation, digital literacy, and technology-based learning evaluation. The presence of these clusters indicates that research in this field is not confined to a single aspect but encompasses multiple dimensions that collectively shape a modern educational ecosystem. The learning technology cluster emerges as one of the most dominant, highlighting the central role of technology as a

foundational element in educational transformation. Topics within this cluster include the development of digital learning media, e-learning platforms, and the integration of technology into instructional processes. This dominance underscores that technology is no longer merely supplementary but has become an integral component of the educational system.

The pedagogical innovation cluster emphasizes the importance of developing teaching methods and strategies that are adaptive to contemporary changes. Research within this cluster focuses on how technology can be utilized to enhance the quality of learning through more creative and learner-centered approaches. This suggests that the success of technology integration depends not only on the tools employed but also on the pedagogical frameworks that guide their use. Furthermore, the digital literacy and technology-based learning evaluation clusters highlight the importance of technological competence and the measurement of learning effectiveness. Digital literacy has become a fundamental requirement for both educators and learners in navigating the digital era, while technology-based evaluation is essential to ensure that learning processes are effective and aligned with intended outcomes (Guo, 2025). Overall, this cluster mapping provides a comprehensive understanding of the direction of research development and highlights opportunities for stronger integration among topics within the field of education and technology.

The discussion on scientific collaboration patterns indicates that collaborative relationships among researchers in the field of education and technology are still largely concentrated within specific institutions or countries. This is evident from the co-authorship analysis, which reveals clusters of authors dominated by the same affiliations. Such a pattern suggests that geographical proximity, institutional similarity, and pre-existing academic networks remain key determinants in establishing research collaborations. This condition is understandable, as collaboration within institutional boundaries tends to be more feasible in terms of communication, coordination, and administrative support. Moreover, shared academic backgrounds and areas of expertise facilitate the process of designing and conducting joint research. However, overly localized collaboration patterns may limit broader knowledge exchange and reduce the diversity of perspectives in advancing scientific inquiry.

The findings also reveal a growing trend of international collaboration in recent years. Advances in communication technologies and improved access to scientific information have enabled researchers from different countries to collaborate more effectively (Judijanto & Nampira, 2025). Cross-national collaboration fosters a richer exchange of knowledge and enhances both the quality and global visibility of scientific publications (Barbu et al., 2022). Overall, collaboration patterns in the field of education and technology demonstrate a shift toward a more open and collaborative research environment. Although local collaboration remains dominant, the increasing level of international cooperation represents a positive indicator for the future development of research (Trivedi et al., 2021). Therefore, more strategic efforts are needed to promote cross-institutional and international collaboration in order to enrich research perspectives and accelerate global scientific progress.

The discussion on future research directions highlights that developments in the field of education and technology will increasingly be driven by the integration of intelligent technologies into learning processes. Cluster analysis

indicates that technologies such as artificial intelligence, machine learning, and learning analytics will serve as key drivers of educational innovation. The application of these technologies enables the creation of more adaptive, efficient, and data-driven learning systems, capable of addressing the demands of the digital era. In addition, personalized learning continues to emerge as a significant area of focus. This approach emphasizes the adaptation of learning processes to individual learners' characteristics, including their abilities, interests, and learning styles. With the support of digital technologies, personalization can be implemented more systematically and accurately, thereby enhancing learner engagement and improving learning outcomes.

The strengthening of 21st-century skills also represents a crucial direction for future research. Skills such as critical thinking, creativity, communication, and collaboration are essential competencies for learners in addressing global challenges. Consequently, research in education and technology is expected to develop learning models that are not only technology-driven but also holistically oriented toward competency development (Karyana et al., 2024). Overall, future research opportunities remain widely open as technological advancements continue to evolve (Guechairi, 2024). The integration of intelligent technologies, personalized learning approaches, and the reinforcement of 21st-century skills indicates that research in this field will continue to grow dynamically (Peker & Yalçın, 2022). This provides ample opportunities for researchers to explore innovative solutions that enhance the quality of education and ensure its relevance in a rapidly changing world.

4. Conclusion

Based on the findings, it can be concluded that research development in the field of education and technology demonstrates an increasingly dynamic and upward trend, with primary focuses on digital learning, artificial intelligence in education, and online learning. The mapping of topic clusters reveals that research in this field is multidimensional, encompassing aspects such as learning technologies, pedagogical innovation, digital literacy, and technology-based evaluation, all of which are interconnected. Furthermore, the analysis of scientific collaboration patterns indicates that although collaborations are still largely dominated by specific institutions and countries, there is a growing trend toward international collaboration that enriches research perspectives and enhances quality. In addition, future research directions suggest that the integration of intelligent technologies, personalized learning, and the strengthening of 21st-century skills will become key priorities in subsequent research development. This indicates that education is undergoing transformation not only in terms of technological adoption but also in pedagogical approaches that are more adaptive and learner-centered. Therefore, research in the field of education and technology holds significant potential for continued growth and for making meaningful contributions toward the development of more innovative, inclusive, and relevant educational systems in the digital era.

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