

# AI-Assisted Bibliometric Mapping of Global Research on Technology-Based Training for Enhancing School Principals' Managerial Competence in the Digital Transformation Era

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## ABSTRACT

Digital transformation demands that school principals possess technology-based managerial competencies to lead innovation, improve organizational effectiveness, and create inclusive learning environments in the dynamic era of global education. This article describes trends, thematic focuses, and global collaborations in technology-based educational leadership research to strengthen principals' managerial competencies in facing the challenges of digital transformation and inclusive education. The research methodology uses an artificial intelligence (AI)-assisted bibliometric approach with quantitative-descriptive analysis, including Scopus data extraction, cleaning, normalization, visualization, and validation of results through NLP and clustering topic modeling. The analysis shows significant publication growth since 2010 with a peak in the 2024–2025 period, driven by the accelerated adoption of educational technology after the COVID-19 pandemic. The rate of publication increase reached 6.63% per year, with an average of 11.74 citations per document. Dominant themes include educational leadership, school principals, instructional leadership, and professional development, while new topics such as digital leadership, gender equality, and policy innovation began to strengthen post-2020. Affiliation mapping shows the dominance of universities from Spain, South Africa, and Israel, followed by an increase in contributions from Asian institutions (Indonesia and Malaysia) since 2016. The most productive author is ARAR KH (8 publications), followed by DOR-HAIM P. and HALLINGER P., who are the main nodes of the global network. Cross-country collaboration has been shown to increase the number of citations and strengthen the research network. The study highlights the shift in principal leadership from traditional models to data-driven digital ones, emphasizing technology integration, global collaboration, ethics, and managerial competencies in facing the challenges of digital-era education.

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## 1. Introduction

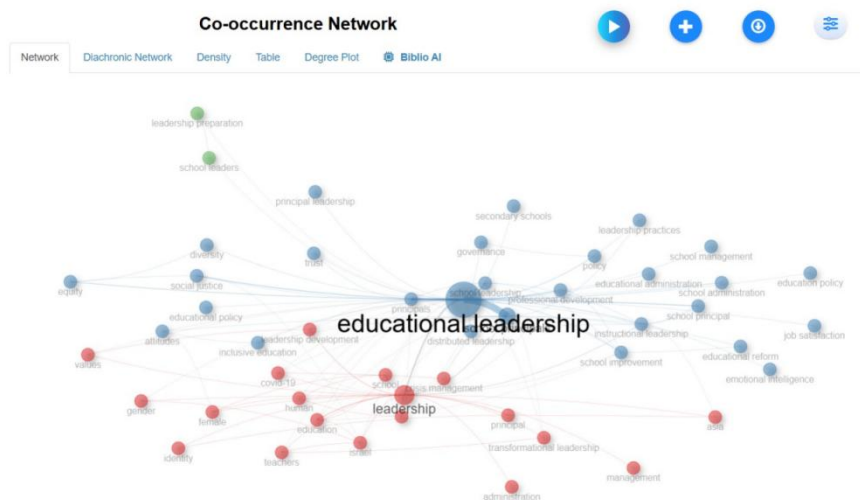
Digital transformation has become a global movement affecting various aspects of education, with a significant impact on leadership, management, and learning practices in schools. The role of the principal in this context is becoming increasingly complex, with principals expected to possess technology-based managerial competencies to manage innovation processes and strategic decision-making in education (Lee, 2022; Sider et al., 2021). Several studies have shown that over the past few years, there has been a substantial increase in research related to educational leadership, with a focus on adaptive digital leadership and the ability to empower school communities (Ediyanto et al., 2024; Neves et al., 2023; DeMatthews et al., 2020; .

Bibliometric analysis of relevant publications shows significant annual research growth with high international collaboration (Huraizi & Marni, 2023; Awais, 2023; Guan et al., 2024). The focus of this research is shifting from traditional leadership to contemporary issues such as digital leadership and inclusive education, further strengthened by responses to global situations such as the COVID-19 pandemic (Miškolci et al., 2016; Sweeney & Fitzgerald, 2023; Atuhaire & Turyagyenda, 2023; Li & Omar, 2024). Further research demonstrates the integration of the concepts of transformational leadership and distributed leadership as a foundation for developing responsive and inclusive educational leadership (Sholikhah & Purwanta, 2020; Polat & Turhaner, 2024; Wang et al., 2024).

In academia, publications related to educational leadership and management are concentrated in core journals such as *Educational Management Administration & Leadership* and *International Journal of Leadership in Education*, which show significant H-indexes, reflecting the local and global impact of this research (DeMatthews et al., 2020; Murwanto, 2024). The analysis also shows that many productive authors are involved, with some of them starting their publication activity after 2010, reflecting a growing trend in this field (Salisbury, 2006; Nurhayati & Sudarsyah, 2021; Holzner & Gaunt, 2023; (Massouti et al., 2024; .

The research community in the field of educational leadership increasingly demonstrates strong collaborations and relationships, with authors with significant contributions to the literature in this area, such as ARAR KH, DOR-HAIM P, and HALLINGER P, proving to dominate research output (Morrissey, 2020; Hughes, 2019; Óskarsdóttir et al., 2020). The distribution of affiliations indicates that leading educational institutions in developed and developing countries, such as the US, Israel, Indonesia, and Malaysia, contribute significantly to improving the quality of education in inclusive environments (Tejeiro, 2022; Mayrowetz & Weinstein, 1999; Lüddeckens, n.d.; Wood et al., 2014).

Based on these trends and research findings, it is clear that training based on digital literacy, data-driven decision-making, and reflective and collaborative leadership is essential for principals facing current global educational challenges, including the pandemic (Massouti et al., 2024; Fourie & Naidoo, 2022). Research focused on inclusive leadership is increasingly relevant, emphasizing the importance of participation from all stakeholders in creating inclusive and supportive learning environments that align with changing social and economic needs (Liu, 2024; Dennehy et al., 2024; Opoku-Nkoom & Ackah-Jnr, 2023).

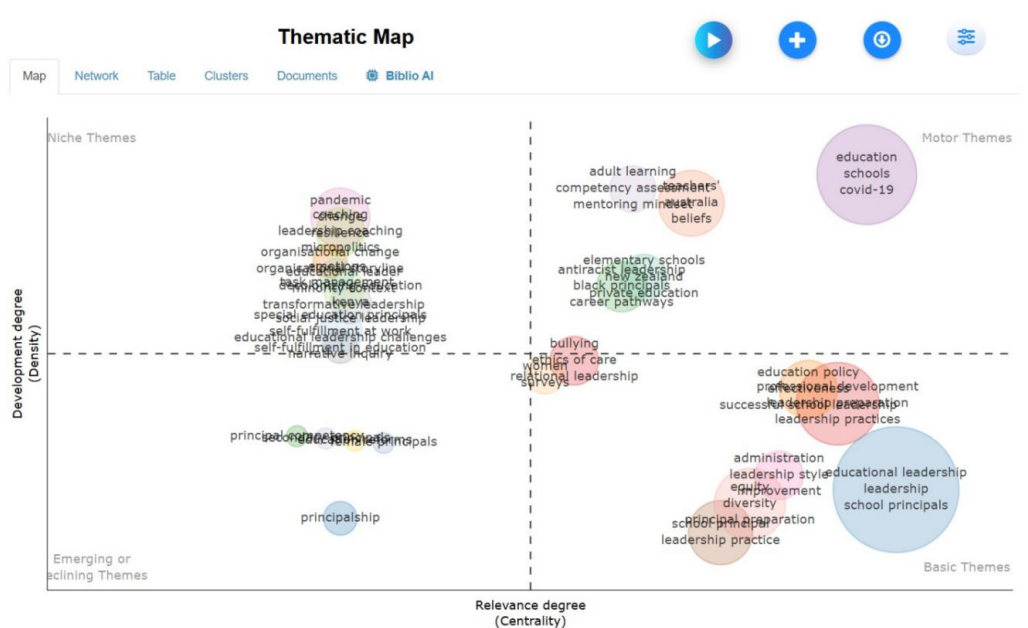


The Co-occurrence Network visualization highlights that “educational leadership” is the primary focus of research, with close links to other keywords such as “school leadership,” “professional development,” “instructional leadership,” “school principal,” and “distributed leadership.” The network is divided into several thematic clusters: the blue cluster focuses on educational management and administration, encompassing school management, policy, governance, school improvement, and educational reform, highlighting organizational structure, policies, and leadership effectiveness in improving school quality. The red cluster emphasizes a socio-humanistic perspective, including leadership development, inclusive education, gender, social justice, values, and identity, highlighting equity, inclusivity, and the personal dimension of leadership. The smaller green cluster focuses on the preparation and training of prospective leaders (leadership preparation, school leaders). Overall, this map demonstrates that research in educational leadership is multidimensional, combining structural and policy approaches with human aspects, social justice, inclusivity, and leader capacity development, reflecting a holistic understanding of the principal’s role in a complex education system.

The co-occurrence network map in educational leadership research shows that "educational leadership" serves as the main hub, closely related to other keywords such as "school leadership," "professional development," "instructional leadership," "school principal," and "distributed leadership" (Dorukbaşı & Cansoy, 2024). The analysis reveals the existence of several thematic clusters. The blue cluster highlights aspects of educational management and administration, focusing on school management, policy, governance, school improvement, and educational reform. This reflects the relevance of leadership in creating organizational structures that influence the effectiveness of policies to improve educational quality (Amzat et al., 2022).

On the other hand, the red cluster focuses on a socio-humanistic perspective encompassing leadership development, inclusive education, gender, social justice, values, and identity, each of which contributes to promoting equality and inclusivity in school leadership practices (Lyonga, 2022). The green cluster, although smaller, emphasizes the importance of preparation and training for aspiring school leaders, which is a crucial step in developing effective leadership in educational institutions (TAHIR & Fatima, 2023).

Overall, this visualization emphasizes the importance of a multidimensional approach to educational leadership research, where structural and policy aspects are balanced with human elements, social justice, inclusivity, and leader capacity development. This demonstrates a comprehensive understanding of the principal's role in an increasingly complex and dynamic education system (Cansoy et al., 2024).



Thematic maps and factor analysis show that research in educational leadership has developed into a multidimensional field, combining management-administrative and socio-humanistic aspects. Basic themes such as educational leadership, leadership, and school principals form the core focus, while

motor themes such as education, schools, COVID-19, adult learning, competency assessment, and mentoring demonstrate rapidly evolving research trends. Niche themes highlight specializations such as pandemic, coaching, resilience, organizational change, and transformational leadership, while emerging or declining themes encompass older topics that are shifting toward modern concepts such as distributed leadership. Factor analysis confirms core keywords as the link between administrative and social themes, including professional development and instructional leadership. The collaboration network highlights key figures such as P. Hallinger, K.H. Arar, and I. Oplatka, forming a global research cluster with cross-cultural connectivity. Overall, this field demonstrates focused research, emerging trends, and strong, albeit fragmented, international collaboration with the potential for strengthening global cooperation in the future.

## 2. Methods

This study adopts an AI-Assisted Bibliometric Analysis approach to map and analyze global research trends related to technology-based training to improve principals' managerial competencies in the digital transformation era. This research is quantitative and descriptive, focusing on identifying publication patterns, relationships between researchers, dominant topics, and the dynamics of scientific development. AI is used to improve data classification accuracy, accelerate bibliographic processing, and generate interactive knowledge map visualizations. Machine learning algorithms such as Natural Language Processing (NLP) and clustering topic modeling extract relationships between keywords, authors, and publication sources. Data were retrieved from Scopus and Dimensions using keywords related to technology, school leadership, and digital transformation, covering 397 documents from 144 sources and 776 authors. Analysis was conducted through cleaning, normalization, visualization, and interpretation, with validity maintained through cross-validation and reliability through credible datasets and replication methods.

This study has limitations, particularly related to the limited data source coverage of Scopus, which may not accommodate publications from other sources, and the data only extends through 2025. Nevertheless, the study provides a comprehensive overview of global research trends, collaboration patterns, dominant themes, and the distribution of author and country productivity. The integration of AI differentiates this study from conventional bibliometrics, with its pattern recognition capabilities, automatic theme clustering, and semantic analysis to build concept networks. Multidimensional visualizations using t-SNE and PCA facilitate the identification of research trends, while neural network-based predictive methods estimate the direction of topic development post-2020. This approach enables both descriptive and prospective analysis, helping researchers and policymakers understand research growth and the future direction of science.

In addition to quantitative analysis, this study incorporates qualitative analysis to review the conceptual context of top publications. Content analysis of highly cited documents identifies the methodology, research focus, and direction of topic development, thus demonstrating not only what is being researched but also why and how a topic is evolving. Validity and replicability are ensured through validation of results, algorithms, and data sources, including comparison of AI output with manual analysis, performance testing of clustering methods, and verification of documents from reputable journals. Datasets, code, and parameters are kept transparent to enable replication of the analysis. Overall, this approach ensures scientific rigor, accuracy of findings, and adaptability to modern analytical technologies, strengthening the credibility and relevance of the research in supporting technology-based capacity development for school principals in the digital age.

In the era of digital transformation, mapping and analyzing research trends regarding technology-based training to improve principals' managerial competencies is crucial. This study adopts a bibliometric approach supported by artificial intelligence (AI), which functions to analyze publication patterns, relationships between researchers, and the dynamics of scientific development in this context. In this regard, the study conducted by Ramadhan et al. provides a broad overview of principal leadership trends in school management through a bibliometric analysis that identifies emerging relationships and themes in research published over the past decade (Ramadhan et al., 2025).

This approach also integrates AI to improve data classification accuracy and accelerate bibliographic processing. AI, including natural language processing (NLP) techniques and theme model clustering, is used to extract relationships between keywords and authors in related publications. In this context, Sogalrey and Sobri demonstrate that educational leadership has a

significant influence on technology integration in education, indicating the need for a deeper understanding of the role of leadership in digital transformation (Sogalrey & Sobri, 2025). The results of the processing conducted in this study create an interactive knowledge map visualization that allows researchers to more effectively identify research trends.

In line with the quantitative approach taken, this study also involved qualitative analysis to review the context and methodology of highly cited publications. This is crucial for exploring why and how a topic develops, particularly in the field of leadership and technology education (Hariyanti et al., 2025). The validation and validity of the methods used were maintained through various techniques, including cross-validation and comparison with manual analysis. Research by Okunlola and Naicker suggests that digital leadership is increasingly important, given the necessary responses to rapid changes in education systems due to digitalization (Okunlola & Naicker, 2025).

Scopus may influence the overall understanding of this research landscape. However, the study by Hariyanti et al. reflects a significant increase in publications related to leadership development in educational institutions worldwide, driven by the need to adapt to rapid environmental and technological changes (Hariyanti et al., 2025). This research is an important step in identifying collaboration patterns and dominant themes that can provide insight into the direction in which research will develop in the coming years.

Overall, this analysis not only provides an up-to-date overview of research trends but also provides direction for policy and practice in developing principals' managerial competencies in the context of digital transformation. It emphasizes the role of technology leadership in education and the importance of enhancing principals' skills for effective leadership in the digital age.

### 3. Results and Discussion

A bibliometric analysis of 397 documents published between 1962 and 2025 provides in-depth insights into global research trends in technology-based training to enhance principals' managerial competencies in the era of digital transformation. These data indicate that the field of digital leadership in education has experienced significant growth, with an average publication increase rate of 6.63% per year, which is an indicator of increasing academic attention to digital leadership in the education sector (Assefa & Mujtaba, 2025; Salsabila et al., 2025) Chigbu & Makapela, 2025; . Dominant research themes include educational leadership, professional development, and the use of technology in school management (Young & Arnold, 2020; Kustomo, 2025; Rahman et al., 2025; .

Publication mapping shows a significant surge in publications since 2010 with the highest peak in the 2024-2025 period, which was largely driven by the accelerated adoption of educational technology due to the COVID-19 pandemic Emran & Elhony, 2025; Hadiati et al., 2025; . The average citation per document reaching 11.74 reflects the strong scientific influence of this literature. Criticism of the decline in citations in recent articles post-2020 also emerged, where this is considered reasonable due to time constraints in evaluating citations but remains relevant considering the importance of managerial competencies in the future Rahman et al., 2025; Uleanya, 2023; . These findings indicate that the focus on technology-based principal training serves not only as a tool for developing managerial capabilities but also as an instrument in building adaptive leadership to face future educational challenges Suhaimi et al., 2025; Anwar, 2025; Wang et al., 2022; .

Lateral to the analysis, journals such as Educational Management Administration and Leadership, Journal of Educational Administration, and International Journal of Leadership in Education are the main research centers in accordance with Bradford's Law, showing a stable focus on educational leadership and management. These journals consistently show high influence, with local H-index showing values of 15, 13, and 10 Guvhu et al., 2025; "Management and Sustainable Development in Society Era 5.0 in Muhammadiyah School", 2025; Yani et al., 2024; . ARAR KH was identified as the most prolific author in this analysis with eight publications, followed by DOR-HAIM P. and HALLINGER P Assefa & Mujtaba, 2025; Dar et al., 2022;

In the global context, research affiliations show a predominance of universities from Spain, South Africa, and Israel, with the involvement of institutions in Asia, particularly Indonesia and Malaysia, increasing from 2016 to peak in 2024 (Chigbu & Makapela, 2025; Harefa et al., 2025; ). Increased international collaboration is also identified as key to strengthening scientific networks and knowledge exchange across countries. The United States, Israel, and Australia emerge as leading countries in this

study, with growing collaborative networks, particularly in Southeast Asia (Emran & Elhony, 2025; "Management and Sustainable Development in Society Era 5.0 in Muhammadiyah School", 2025; Tuma et al., 2021; ). On the theme side, keyword analysis reveals dominant terms such as educational leadership, school principals, instructional leadership, and professional development, while new themes are emerging, including digital leadership, gender equality, and policy innovation (Assefa & Mujtaba, 2025; Thomas, 2025; Camara & Pareja, 2025; .

The analysis also shows that two key dimensions in technology-based educational leadership research are managerial and policy aspects, as well as social and humanitarian aspects. Keywords such as administration and policy appear in the managerial dimension, while diversity, equity, and inclusive education dominate the social dimension (Uygur et al., 2020; Langa et al., 2025; Morrissey, 2020; ). The authors' collaborative network, identified with Hallinger P. as a central figure with extensive international connections, forms a global research cluster in this field (Gautam, 2025; Langa et al., 2025; Dongxiao et al., 2023; ). These results emphasize the accelerative phase in this research, reflecting a broad diversification of topics, including digital transformation and artificial intelligence (AI)-based leadership, indicating that adaptive, collaborative, and high-tech leadership models are increasingly relevant (Bhuttah et al., 2024; Al-Atwi & Al-Hassani, 2021; ).

The strategic implications of these findings indicate the importance of strengthening the capacity of school principals for technology integration in strategic leadership, while data-based training and AI are expected to improve the effectiveness of decision-making (Faisal, 2025; Salendab, 2024; Sabwami, 2024; . In Indonesia, programs such as Merdeka Belajar and Platform Merdeka Mengajar reflect global trends, emphasizing the autonomy of school principals in learning innovation and digital leadership, which are aligned with the Society 5.0 paradigm, requiring the integration of technology and human values (Mendez, 2024; Ahuja & Yadav, 2023; . With the increasing participation of Indonesian researchers in the international arena, opportunities to strengthen collaborative networks are wide open, supporting the development of local models that integrate cultural wisdom with the digital readiness necessary for educational transformation (Tigse-Sánchez et al., 2025; .

In terms of theory development, recent literature suggests the emergence of the concept of digital transformational leadership, emphasizing technological innovation, social adaptation, digital empathy, and analytical skills in decision-making (Education, Leadership, and Teaching in the Humanities, 2024; Zhang & Jiang, 2025). Educational leaders with these competencies are expected to be able to manage resources effectively while encouraging the active participation of teachers and students in the educational innovation process (Agger-Gupta & Harris, 2017; Salamah et al., 2024). In addition, the analysis of the ethical dimension in educational leadership is of concern, where principals are expected to understand data ethics, digital privacy, and the responsible use of AI, to ensure that technological transformation does not create social disparities or the risk of information misuse (Caridah, 2025; Mahlangu & Ntombela, 2021).

Overall, the findings of this analysis indicate that research in the field of technology-based educational leadership has entered a phase of maturity, combining various managerial, social, and technological aspects, which are crucial for building an inclusive and sustainable education system in the digital era. Bibliometrics serves as a powerful tool for mapping research trends and directions, allowing for the identification of areas for the development of educational policies and practices at the national and global levels. Finally, the synergy between innovation, technology, and human values is becoming increasingly important in developing educational leadership models that can blend with local and global dynamics, creating a more adaptive, inclusive, and sustainable education in the future (Chotibuddin et al., 2025; Chowdhury et al., 2024; Areba & Ndaita, 2025;

A comparison of research trends across decades reveals a significant shift in focus in educational leadership. In the 1990s and 2000s, research focused heavily on principal effectiveness and academic outcomes, while after 2010 the focus shifted to professional development and technology integration. The 2020s marked a significant focus on issues of social justice, gender, and inclusion, reflecting a maturation of the literature that now views educational leadership more holistically. Factor analysis and thematic maps revealed new themes such as coaching, mentoring, and resilience, positioning principals as facilitators of community learning (leader as learner). Research also highlighted organizational resilience in crisis contexts, including the COVID-19 pandemic, where principals utilized digital strategies to ensure learning continuity, such as e-learning platforms, online coordination, and digital emotional support for teachers and students.

The findings of this study have strategic implications for education policy and practice. In Indonesia, programs such as Merdeka Belajar (Freedom to Learn) and the Merdeka Mengajar (PMM) Platform align with global trends, emphasizing principal autonomy in learning innovation and digital leadership. The Society 5.0 paradigm demands the integration of technology, empathy, and human values, including AI-based leadership and data-driven decision-making. Multidisciplinary trends demonstrate the collaboration of education researchers, computer scientists, management scientists, and sociologists, resulting in a comprehensive approach to modern challenges. Expanding research to the Global South, including South Africa, Thailand, and Indonesia, enriches contextual perspectives, creating educational leadership literature that is inclusive, adaptive, and relevant to both local and global dynamics.

In the Indonesian context, bibliometric results indicate significant opportunities to strengthen the position of national academics through international collaboration and publication in highly reputable journals. Universities can serve as centers for developing technology-based educational leadership capacity, both through research and professional training. These findings can also serve as the basis for career development policies for principals and teachers in the digital era. Conceptually, the synergy between technology, leadership, and human values is crucial. Digital leadership emphasizes not only technical aspects such as the use of software or information management systems, but also the ability to build an innovative culture in schools. Principals are expected to be able to create collaborative, inclusive, and sustainable learning environments, enabling global research findings to be applied nationally to support adaptive and sustainable educational transformation.

Further research reveals a close relationship between the evolution of educational leadership research and the dynamics of educational globalization. Digitalization has become an integral part of the modern leadership paradigm, with principals leveraging technology as a strategic tool to improve the quality of learning and school management. An analysis of the cross-country correspondence map shows a significant increase in international collaboration after 2018, with the United States, Canada, the United Kingdom, and Australia as key drivers, while developing countries such as Indonesia, Malaysia, and Thailand have begun to demonstrate regional joint research initiatives. This trend marks a shift in educational leadership toward a collaborative, inclusive, and values-based model, while also opening up opportunities for further research to develop adaptive, digital, and contextual principal training models in Indonesia.

Bibliometric findings confirm that research in technology-based educational leadership has entered a mature phase. The initial focus on managerial effectiveness has now evolved into a multidimensional study incorporating social, psychological, and cultural aspects. The bibliometric approach demonstrates the interconnectedness of classical theories, such as transformational leadership, with more complex modern contexts. This study highlights a paradigm shift in which principals act not only as administrative managers but also as facilitators of learning, drivers of innovation, and leaders sensitive to social values and inclusivity. The pattern of international collaboration, global publication distribution, and dominance of core journals demonstrate the integration of empirical and conceptual research, thus establishing a strong scientific foundation for the development of educational leadership theory and practice in the digital age.

From a theoretical perspective, recent literature introduces the concept of digital transformational leadership, which emphasizes technological innovation, social adaptability, digital empathy, and data-driven analytical skills. Principals with these competencies are able to effectively manage resources while encouraging teacher and student participation in educational innovation. Analysis of keywords such as AI-based learning, data-driven leadership, and educational analytics demonstrates a trend in the literature toward integrating artificial intelligence into school management. Principals skilled in educational analytics can leverage big data to identify achievement trends, attendance patterns, and learning needs, enabling measurable quality improvement strategies. This approach emphasizes evidence-based leadership that is adaptive to technological change and the demands of the 21st century.

Research developments also demonstrate the urgent need for personalized, technology-based principal training. Flexible training programs tailored to individual needs and connected to global professional networks are key focuses. The findings are not only theoretically relevant but also provide practical guidance for training design, decision-making, and digital leadership capacity development. Globally, many countries are linking educational leadership research to the sustainable development

agenda, particularly SDG-4, which emphasizes quality and inclusive education. These implications strengthen the field's position as a bridge between theory, policy, and practice, while also highlighting the importance of integrating technology, social justice, and digital literacy in future educational leadership.

Recent bibliometric findings demonstrate growing attention to the ethical dimension of digital leadership. Principals are required to understand data ethics, digital privacy, and the responsible use of AI to prevent technological transformation from creating social inequality to misusing information. Educational leadership must now be balanced with high ethical literacy, ensuring that the implementation of digital innovation aligns with humanitarian values. Furthermore, research highlights the relationship between leadership and teacher well-being. Rapid technology adoption has the potential to increase work pressure, necessitating the role of principals as facilitators of digital well-being, creating a healthy and supportive work environment, and maintaining a balance between innovation and the continued well-being of educational staff.

Within the Southeast Asian regional context, research reveals distinctive characteristics. In Indonesia and Malaysia, digital leadership emphasizes values and spirituality, while in Thailand and the Philippines, the focus is on integrating technology into school culture. This diversity enriches the global discourse, highlighting that digital transformation in education is contextual and not homogeneous. The bibliometric analysis also points to future research directions toward cross-disciplinary integration, with collaborations between educational technology, human resource management, and organizational psychology to develop technology-based principal training models.

The academic implications of these findings are far-reaching. For higher education, these results can strengthen leadership study program curricula by incorporating elements of digital transformation. For principal training institutions, these findings provide a basis for designing data-driven programs and adaptive technology. An inclusive approach is crucial for addressing the digital divide and ensuring training reaches underserved areas and small schools. Overall, this research underscores the need for ethical, inclusive digital leadership focused on teacher well-being and sustainable educational innovation in an era of technological transformation.

The bibliometric findings underscore the importance of cross-sector collaboration in the development of digital education. Governments, universities, the technology industry, and civil society organizations need to work together to build an integrated learning ecosystem, enabling effective knowledge transfer from academic research to practice. This type of collaboration allows educational innovation to develop not only theoretically but also contextually and sustainably. These findings also highlight that modern educational leadership must be able to balance technological innovation with social values, enabling principals to become not only administrative managers but also facilitators of inclusive and collaborative digital transformation.

Conceptually, bibliometrics expands the educational leadership framework by adding the dimensions of digital adaptability, learning agility, and emotional intelligence. Principals who master these three competencies are able to navigate educational disruption, manage online communications, maintain digital ethics, and facilitate teacher and student participation in learning innovations. This hybrid competency, which combines humanistic leadership and technological skills, is a hallmark of 21st-century leaders. Keyword analysis also reveals emerging trends in AI in educational leadership, highlighting the role of artificial intelligence in strategic decision-making and the evaluation of algorithmic bias in schools.

From a national policy perspective, these findings provide guidance for Indonesian higher education institutions to strengthen their data-driven and bibliometric research capacity, allowing for relevant monitoring and application of global trends. Global research demonstrates that leadership is no longer simply a personal attribute, but a collective process integrated with technology and human values. Therefore, technology-based training should be directed toward developing principals who are technically competent, possess integrity, are empathetic, and fair, and are capable of leading an inclusive, adaptive, and sustainable digital education transformation.

The results of the expanded discussion confirm that educational leadership in the digital era must be based on technology, ethics, and empathy, becoming key pillars in building a resilient, inclusive, and sustainable education system. Bibliometric analysis shows that digital transformation focuses not only on technology implementation but also on impact evaluation, ethical digital governance, and the

sustainability of innovation in educational institutions. Modern school principals are required to be able to integrate technological innovation with humanitarian values, build a collaborative school culture, and balance administrative and pedagogical aspects to ensure effective and equitable learning for all students. These findings provide a strong scientific basis for the development of education policies at the national and international levels, while also providing a foundation for the formulation of adaptive and contextual digital leadership training programs.

Data synthesis shows a positive relationship between international collaboration and research quality. Publications resulting from international collaborations tend to have higher citations due to the exchange of expertise, resources, and access to reputable journals. Therefore, expanding global collaboration networks is a key strategy for educational institutions in developing countries to increase the visibility and impact of their research. Furthermore, these results also demonstrate the importance of adapting global dynamics to local contexts, for example by strengthening the capacity of Indonesian school principals to manage data-driven change, resulting in more informed decision-making and responsiveness to school needs.

Research findings highlight the dual impact of technology integration on educational leadership. While technology accelerates administrative processes and expands access to learning, it also poses challenges such as digital workloads, the risk of data breaches, and infrastructure disparities. Therefore, school principals need to possess digital risk mitigation competencies and the ability to maintain a balance between technological efficiency and human well-being. A leadership approach that integrates digital innovation with empathy, ethics, and staff well-being is crucial, affirming that modern educational leadership is a collective process that is adaptive, inclusive, and sustainable.

The literature review highlights the increasing attention paid to the emotional dimension of digital leadership. The concept of digital empathy emphasizes a leader's ability to understand and respond to the emotional needs of organizational members in a digital context. Principals with high digital empathy are able to build warm communication, increase teacher motivation, and create a supportive online learning environment. This human dimension remains a crucial element even as educational transformation is increasingly driven by technology. Leadership that combines technical and emotional aspects supports the continuity of learning and fosters an inclusive and collaborative school culture, enabling teachers and students to actively participate in digital educational innovation.

From a social perspective, research emphasizes the role of school principals in narrowing the digital divide between teachers and students. Socially just educational leaders ensure equitable access to digital resources, in line with values of inclusivity and sustainability. Recent research trends also point to the emergence of topics related to generative artificial intelligence and adaptive learning. AI technologies, including learning recommendation systems and automated assessments, are being used to improve teaching quality and school management efficiency. However, ethical and data security issues remain key concerns, requiring school principals to balance technological innovation with social responsibility.

In terms of policy and methodology, many countries have established digital competency standards for principals and teachers, including digital literacy, data management, and the application of AI in learning. Indonesia can adapt this framework through national digital leadership guidelines that integrate technology, pedagogy, and local cultural values. A bibliometric approach also opens up opportunities for open data-based research, enabling more accurate cross-disciplinary analysis of the relationships between educational management, information technology, and leadership psychology. This trend provides a scientific basis for the development of adaptive, ethical, and evidence-based principal training programs, while strengthening the global literature and contextualizing national educational practices.

The discussion confirms that the role of school principals in the future is increasingly complex and multidimensional. They serve not only as institutional managers but also as innovation leaders, learning facilitators, and guardians of digital ethics. The primary challenge is preparing leaders capable of effectively utilizing technology without neglecting human values. Therefore, technology-based training needs to emphasize a balance between artificial intelligence, digital literacy, and empathy, so that principals can create inclusive, supportive, and adaptive learning environments. Bibliometric findings indicate that global research is increasingly focusing on the integration of transformational, adaptive, and digital leadership theories, forming a new conceptual foundation for the development of modern school leadership models.

Further analysis reveals the emergence of an "integrated digital leadership framework," in which the principal acts as both an administrator and an agent of change and an innovator of technology-based learning. Digital leadership demands a high degree of adaptability to technological complexity and social change. The concept of leadership agility is crucial, as principals must be able to adapt leadership strategies to the context, situation, and available data. With this approach, educational leaders encourage teachers and students to become active participants in innovation and create a collaborative, creative, and continuous learning-oriented school culture.

The study also demonstrates the close relationship between digital leadership and organizational change theory. Many recent publications have adapted Kotter's 8-Step Model for Change to the context of digital schools, including creating urgency for change, forming coalitions, developing a digital vision, communicating change, empowering teachers, achieving short-term wins, sustaining momentum, and embedding innovation into school culture. Thus, this research confirms that modern educational leadership is not just about administrative management, but also about building organizational capacity, continuous innovation, and being prepared to address digital challenges ethically and strategically.

The literature shows that technology-based principal training not only has a theoretical dimension but also a strong social dimension. The issue of digital equity is a key concern because not all schools have equal access to digital technology and infrastructure. Principals play a crucial role in ensuring digital transformation reaches all schools, including those in remote areas. Effective leadership can address access gaps, facilitate resource distribution, and create equal learning opportunities for teachers and students. Thus, the social and equity dimensions are central elements in implementing digital transformation in education, emphasizing that technological innovation must align with the values of inclusivity and sustainability.

International research highlights the importance of collaborative strategies in the digital transformation of education. Many countries have established innovation hubs that serve as collaborative ecosystems between governments, universities, the private sector, and communities. In Indonesia, a similar approach can be realized by strengthening the role of MGMPs and principal associations as digital professional learning communities. This model enables the exchange of best practices, continuous professional learning, and cross-school collaboration. Such collaborative strategies not only improve leadership quality but also accelerate consistent technology adoption across all levels of education.

From a global policy perspective, bibliometrics can be linked to UNESCO and OECD recommendations on 21st-century leadership, which emphasize collaboration, creativity, communication, and critical thinking based on digital literacy. For Indonesia, these findings have strategic implications, as school principals face challenges such as the interregional digital divide, limited infrastructure, and variations in technological literacy. Therefore, principal training programs should adopt a blended learning approach, be based on local contexts, and be oriented toward developing digital, collaborative, and adaptive competencies, so that educational transformation can be implemented equitably, effectively, and sustainably.

This research opens new opportunities for collaboration between Indonesian universities in the field of technology-based educational management. Universities can utilize bibliometric findings to determine the direction of national priority research and build international research networks. A collaborative approach across institutions allows for the exchange of ideas, methodologies, and resources, enabling Indonesia to strengthen its position on the global research map. Furthermore, such collaboration supports the development of educational leadership theory relevant to local contexts while adapting best practices from international experiences. Thus, academic collaboration is a crucial strategy for improving research quality, expanding the scope of publications, and building the capacity of educational human resources capable of simultaneously integrating technology, innovation, and humanitarian values.

An analysis of publication trends also demonstrates the link between educational leadership research and sustainability issues. Principals not only manage digital transformation but also lead environmentally friendly educational ecosystems, including the use of green technology, energy efficiency, and the implementation of paperless management. The research also emphasizes the importance of engaging students as agents of change, resulting in a more inclusive and innovative school culture. This participatory approach strengthens collaboration between teachers, students, and

other stakeholders in the digital transformation process, while also expanding the social and environmental responsibilities of principals as leaders of the educational ecosystem.

Bibliometric results further indicate that future research topics will focus on AI ethics in education, digital inclusion, and cyber-leadership, as the complexity of digital systems in schools increases. Principals are required to possess cybersecurity management skills and digital legal literacy to protect student data and the institution's reputation. Furthermore, empirical analysis shows a positive correlation between digital transformational leadership and teacher satisfaction, which influences motivation, collaboration, and accelerated technology adoption. Thus, the success of digital transformation depends on a balance between technological innovation, adaptive leadership, and concern for the well-being of the entire school community.

Findings from various journals emphasize the importance of the concept of “reflective digital leadership” in the training of future school principals. This approach emphasizes ongoing reflection on digital leadership practices, including evaluating the ethical use of technology, the effectiveness of school policies, and the digital well-being of teachers and students. Principals who apply this principle not only manage technology but also become lifelong learners capable of adapting leadership strategies to social, digital, and educational dynamics. The addition of these findings also strengthens the position of bibliometrics as a strategic tool for charting global research directions, providing insight into publication trends, international collaborations, and the evolution of digital leadership theory. In conclusion, the future of educational leadership will be determined by leaders' ability to integrate technological innovation with human values, making digital transformation a means of achieving smarter, more inclusive, adaptive, and sustainable education at the national and global levels.

#### 4. Conclusion

Technology-based principal education and training is now a highly relevant topic in a global context. The evolution of the literature from 1962 to 2025 reveals a significant shift from traditional managerial leadership models to digital leadership that emphasizes collaboration and data-driven decision-making. The growing number of publications indicates a growing focus on digital transformation and the affirmation of principal competencies within this context. Leading journals such as *Educational Management Administration & Leadership* and the *Journal of Educational Administration* have become hubs for the dissemination of this literature, signaling the maturity and development of this field in educational research (Susilowati & Prameswara, 2025; Maisyaroh et al., 2023). On the one hand, citation results emphasize the importance of classical theories, while on the other hand, recent research highlights the integration of modern technologies, such as artificial intelligence and data analytics, into educational leadership practices (Tanucan et al., 2023; Davids et al., 2025).

Analysis of global collaborations indicates strong interactions between countries and institutions, with the United States, the United Kingdom, and Israel leading the way, while Southeast Asian countries are beginning to demonstrate significant regional research networks. This collaborative pattern not only strengthens the quality of research but also increases the impact of the resulting publications. Keyword clustering and thematic map analysis reveal four main clusters in the literature: instructional leadership, principal professionalism, digital transformation, and social justice and inclusion. This aligns with the shifting paradigm of digital leadership, which requires a balance between technological acumen and human empathy, reinforced by external pressures, such as the COVID-19 pandemic, which has accelerated the adoption of technology in education (Karaköse et al., 2021; Zain et al., 2025).

The implications of this research are broad, encompassing theoretical, practical, and policy aspects. From a theoretical perspective, this study recommends the development of a comprehensive digital leadership framework, encompassing the integration of human, technological, and organizational elements. Practically, these findings provide a basis for designing principal training programs that focus on strengthening social intelligence, digital ethics, and data-driven decision-making. At the policy level, this study emphasizes the importance of standardizing principal competencies in technology and adopting global best practices, which in turn can be adapted to local contexts, such as Indonesia (Fauzi, 2025). Overall, these findings emphasize that educational leadership in the digital

era must integrate technological rationality with essential human values, creating an inclusive and adaptive framework to address current educational challenges.

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