

## Global Research Trends in Technology-Enhanced Learning (2020–2024): A Bibliometric Mapping Analysis

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**Abstract:** This study analyzes global research trends on Technology-Enhanced Learning (TEL) from 2020 to 2024 using a bibliometric mapping approach. Data were extracted from the Scopus database with the query TITLE-ABS-KEY (“technology-education” AND “learning”), yielding 747 valid documents consisting of journal articles, conference papers, and book chapters. The analysis employed Microsoft Excel, VOSviewer, and Biblioshiny to examine publication performance, collaboration networks, and thematic evolution. Results indicate a steady growth of research output, reflecting an increasing global commitment to educational transformation driven by digital innovation and artificial intelligence. The United States, China, and India emerged as the most productive countries, while leading sources such as *Computers & Education* and *Educational Technology Research and Development* dominated the publication landscape. Keyword co-occurrence mapping revealed seven thematic clusters, with *e-learning*, *artificial intelligence*, *digital pedagogy*, and *STEM education* as the most prominent themes. The findings highlight a paradigm shift from emergency remote learning during the pandemic to a sustainable integration of technology into pedagogical design. This study provides a foundational map for researchers and policymakers to navigate the evolving intellectual structure of TEL and highlights underexplored areas such as ethical AI implementation in Global South contexts and the limited empirical evidence on teacher readiness for advanced learning analytics.

**Keywords:** Digital Pedagogy, Educational Technology, Learning Analytics

### A. Introduction

The integration of technology in education has fundamentally reshaped how knowledge is created, accessed, and shared in the 21st century. Rapid advancements in artificial intelligence (AI), digital platforms, virtual learning environments (VLEs), and smart classroom systems have redefined global learning ecosystems (Cunha et al., 2020; Lombardi, 2021; Omol, 2024). This digital transformation has encouraged educational institutions to shift from conventional instructional models toward more adaptive, inclusive, and interactive learning environments (Murdan, 2024). Technologies associated with Industry 4.0 and Industry 5.0, including robotics, data

analytics, and the Internet of Things (IoT), have contributed to new forms of lifelong learning and employability (N. R. A. da Silva et al., 2020; J. Lu et al., 2021). At the same time, these innovations support individualized learning and foster active engagement consistent with constructivist and socio-cultural learning theories (Gui et al., 2024; Kaniadakis & Padumadasa, 2022; Sarzhanova et al., 2025). In this study, these theoretical frameworks serve as an anchor for interpreting the bibliometric patterns; clusters related to *active learning*, *project-based learning*, or *collaboration*, for example, will be examined as empirical manifestations of constructivist and socio-cultural principles.

Emerging technologies such as virtual and augmented reality (VR/AR) have also strengthened student motivation, participation, and conceptual understanding across disciplines (Lampropoulos, 2024; Lampropoulos et al., 2023). VR-based learning environments have demonstrated significant benefits for computational thinking and problem-solving within STEM fields (Cheng & Kinoshita, 2024; Ješková et al., 2024). Similarly, AI-driven adaptive learning systems enable personalized learning pathways that address disparities in pace, access, and readiness (Chen & Chen, 2024; Hasan et al., 2021; Simbolon et al., 2025). Growing concerns regarding fairness, transparency, and inclusiveness have introduced an important ethical dimension to the integration of AI in education (Nguyen Thi Thu et al., 2023; Perkins et al., 2024; Rahmawati et al., 2024). These developments underscore that educational transformation constitutes not only a technological shift but also a social, cultural, and ethical one – requiring careful examination of how innovation aligns with human-centered learning values.

Despite substantial progress, current research on technology-based education remains fragmented. Many studies concentrate on isolated tools such as gamification, AI tutoring, VR labs, or digital literacy interventions without offering a comprehensive view of the field's structural evolution (Rosak-Szyrocka, 2024). Existing reviews are mostly narrative or focus on specific sub-domains like AI in education, VR/AR applications, or remote learning environments (Esh & Ghosh, 2024; Salomova, 2025). Consequently, there is limited understanding of broader publication trends, collaboration patterns, or thematic trajectories in Technology in Learning (TEL) research. This fragmentation is further compounded by persistent regional inequalities in infrastructure, digital literacy, and teacher readiness (Balykbayev et al., 2022; Bunjaku et al., 2024; Maricic et al., 2024). Ethical concerns related to data privacy, algorithmic bias, and the responsible use of AI – particularly generative systems such as ChatGPT – remain insufficiently explored in empirical research (Liu & Wang, 2024; Morley et al., 2019; Vrabie, 2023). These gaps highlight the need for a comprehensive, data-driven, and visual analytical approach capable of mapping the global evolution of TEL research in the post-pandemic era.

Between 2020 and 2024, educational technology experienced unprecedented

acceleration. The COVID-19 pandemic played a catalytic role, compelling educational institutions worldwide to implement online and blended learning at scale (Diz-Otero et al., 2023; Sy et al., 2022). Digital competencies, connectivity, and platform readiness emerged as essential prerequisites for participation in learning (Fong et al., 2024; Nurazmi, Hamid, et al., 2025). At the same time, renewed interest in maker education, experiential learning, and gamification has reinforced the importance of student-centered pedagogical models (David, 2025; Krath et al., 2021; Liao et al., 2021). Recent studies also emphasize the growing integration of AI and generative systems into instructional design, assessment, and content development, supporting computational literacy and creativity (Alberd et al., 2024; Benjamin et al., 2024). Bibliometric investigations reveal an increasing global focus on digital literacy, assistive technologies, and ethical AI, demonstrating the complex interplay between innovation, inclusion, and sustainability in TEL research (Hamid et al., 2022; Rosak-Szyrocka, 2024; W. Zhao & Liu, 2024).

Within this rapidly evolving context, the present study offers a unique contribution by providing a comprehensive bibliometric mapping of global TEL research from 2020 to 2024. While previous reviews have been limited to narrow sub-fields or qualitative analyses, few studies have employed large-scale quantitative techniques to visualize the structural, conceptual, and thematic evolution of the TEL landscape. Using VOSviewer and Biblioshiny, this research maps co-authorship networks, keyword co-occurrence patterns, and thematic clusters to illuminate the intellectual structure of the field. Furthermore, this study provides a *post-pandemic baseline* that captures how educational technology research has matured after the COVID-19 disruption offering a valuable reference point for tracking future developments in digital pedagogy, human-technology interaction, and ethical innovation.

Beyond describing publication patterns, this study aims to generate actionable insights for policymakers, educators, and researchers as they navigate the complex challenges of educational transformation. By uncovering global collaboration trends and emergent conceptual directions, this research helps contextualize ongoing debates regarding digital equity, AI ethics, and sustainable learning ecosystems. It also establishes an empirical foundation for future research seeking to integrate pedagogy, technology, and ethics within a cohesive and theoretically informed agenda.

Based on this background, the study addresses the following research questions: 1) How has research output on Technology in Learning evolved between 2020 and 2024? 2) Which source titles, authors, and institutions have contributed most significantly to the field? 3) Which countries demonstrate the highest productivity and collaboration intensity? 4) What are the most frequently occurring keywords and dominant research themes? 5) How do bibliometric patterns illustrate the conceptual and thematic evolution of Technology in Learning during this period?

## B. Methods

This research was conducted to analyze global trends in TEL during the period 2020–2024 using a bibliometric mapping approach. This method was selected because it provides a systematic, objective, and quantitative way to study a large number of scientific publications, allowing the researcher to identify intellectual structures, collaboration networks, and emerging research themes in the field of educational technology (Nurazmi, Bancong, et al., 2025; Suelves et al., 2020; Yadav et al., 2023). The object of analysis consisted of bibliographic records indexed in the Scopus database (<https://www.scopus.com>). These records replaced conventional human respondents because the research focused on analyzing documents rather than individual perceptions or behaviors. Each record whether a journal article, conference paper, or book chapter represented a research contribution that collectively defined the intellectual development of TEL from 2020 to 2024.

The data collection process began with the formulation of a clear and targeted search query. The researcher used the Boolean command:

TITLE-ABS-KEY (“technology-education” AND “learning”)

This query ensured that all retrieved documents contained both “technology-education” and “learning” in their title, abstract, or keywords, thus maintaining topic relevance. The search was executed on April 29, 2025, and initially produced 2,174 records. These records represented publications across multiple disciplines, including education, computer science, and the social sciences.

To maintain data accuracy and focus, a set of inclusion and exclusion criteria was applied. Only documents published between 2020 and 2024 were included, document types were restricted to *journal articles*, *conference papers*, and *book chapters*, which represent primary research outputs containing original findings. Other document types such as reviews, editorials, notes, and errata were excluded to preserve analytical consistency. Only English-language publications were retained to ensure linguistic uniformity and comparability across records. After applying these criteria, 747 documents were considered valid and included in the final dataset. The files were then processed and analyzed using three main analytical instruments: Microsoft Excel, VOSviewer, and Biblioshiny.

To ensure data validity and reliability, all steps in the data collection and analysis process were documented in detail shown in figure 1. The search and filtering procedures were performed on the same day to avoid inconsistencies caused by database updates. The inclusion criteria were clearly defined and applied consistently, while all processed files were stored securely for verification and replication. In addition, the integration of VOSviewer and Biblioshiny provided triangulation of findings VOSviewer focusing on visualization and structure, while Biblioshiny emphasized performance and trend metrics—thereby enhancing methodological

robustness. Because this study relied entirely on bibliographic data from Scopus, no human participants were involved, and thus ethical approval was not required.

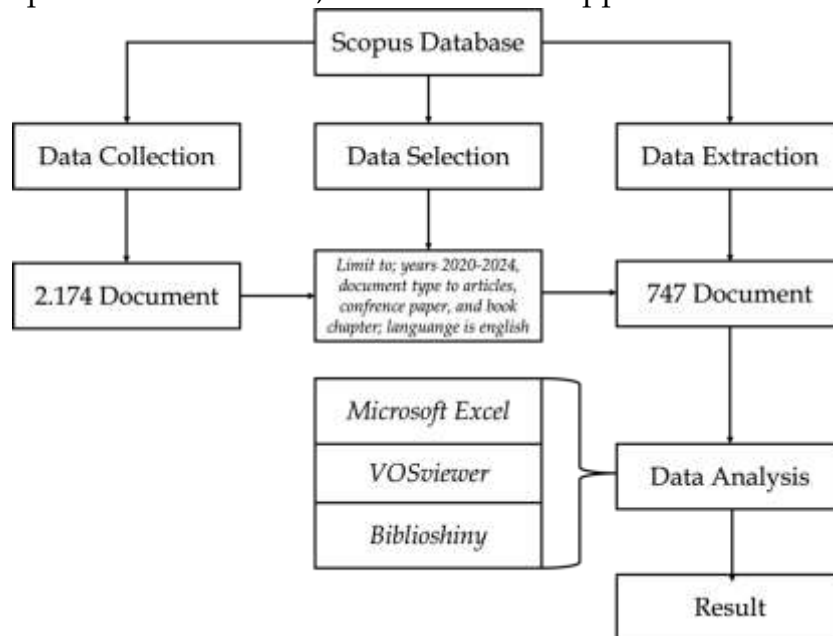


Figure 1 The steps in collecting and analyzing the data

## C. Results and Discussion

### 1. Results

#### 1.1 Publication Output and General Patterns (2020–2024)

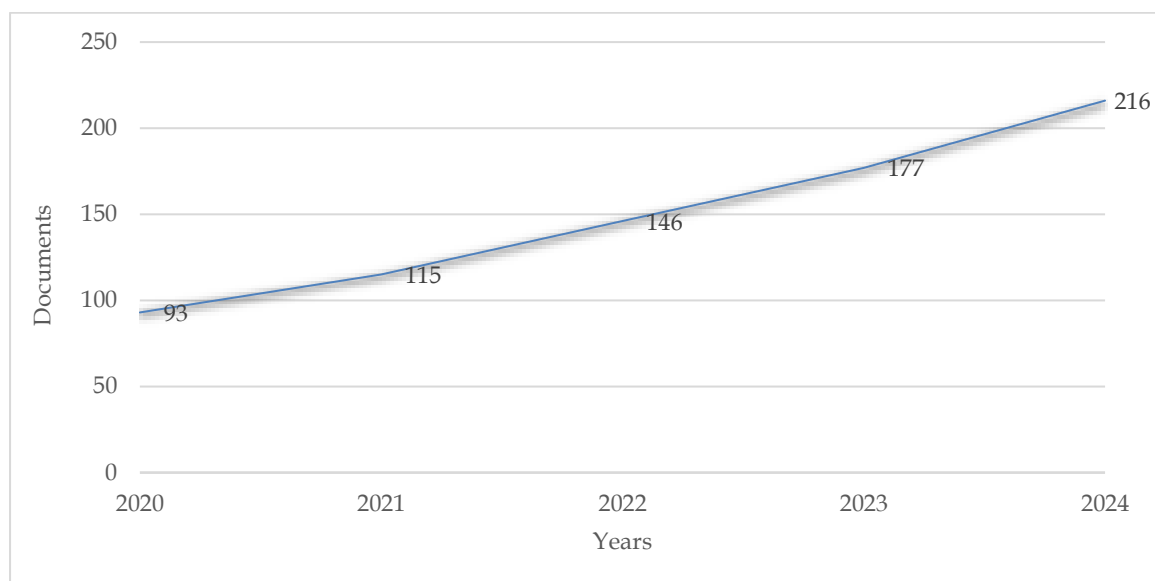


Figure 2 Number of Articles Published Each Year

The increasing integration of technology in education has not only enhanced teaching and learning processes but also prepared students to meet the demands of a digital workforce. This transformation has occurred progressively, with blended learning emerging as a dominant instructional model in the post-pandemic era. In 2020, the onset of the COVID-19 pandemic disrupted academic routines and resulted in a lower research output, with only 93 documents published. This initial decline was likely due to institutional transitions to digital platforms, which temporarily delayed scholarly activity. By 2021, as institutions adjusted to remote modalities, publication numbers increased to 115, reflecting improved adaptability among educators and researchers.

The year 2022 marked a period of significant recovery and adaptation, with publication output rising to 146. At this point, many educational systems had embedded digital tools such as online assessments and learning management systems (LMS) into their pedagogical frameworks. In 2023, the upward trajectory continued, with 177 documents published. This phase was characterized by deeper inquiries into advanced technologies such as Artificial Intelligence (AI), Virtual Reality (VR), and adaptive learning systems. In 2024, publication output peaked at 216, indicating sustained interest in digital education. This surge corresponded with post-pandemic recovery efforts and heightened attention to digital equity, student well-being, and long-term technology adoption strategies. The consistent growth in publication numbers from 2020 to 2024 illustrates a broadening research agenda that includes both technological innovation and its pedagogical implications. In line with the literature, we observe a sustained emphasis on online, blended, and hybrid learning across the window, accompanied by a growing presence of AI-augmented teaching/assessment, immersive media (VR/AR), and skills frameworks (STEM/STEAM). In bibliometric terms, these patterns are reflected not only in the topical vocabulary (keywords) but also in the clustering tendencies evident in co-occurrence analyses (figure 8), where networks align around post-pandemic digital learning infrastructures, AI/analytics in education, and maker/experiential pedagogies.

## **1.2 Performance Snapshot: Sources, Authors, and Institutions**

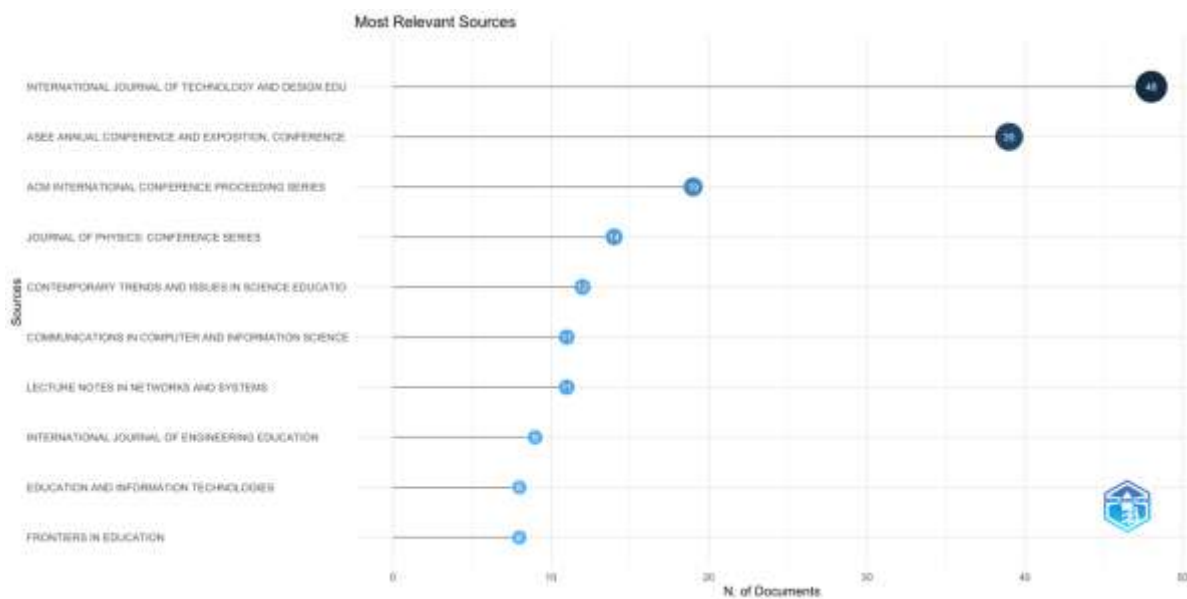
The bibliometric analysis reveals a rich and diverse landscape of scholarly contributions to *TEL* between 2020 and 2024

### **1.2.1 Sources Performance**

The first layer of performance analysis focuses on source titles—the journals and conference proceedings that have most frequently published *TEL*-related studies. Figure 3 illustrates the *Most Relevant Sources* during the study period. It shows a concentration of publications in long-established journals in educational technology (e.g., *Computers & Education*, *Educational Technology Research and Development*, *International Journal of Emerging Technologies in Learning*) alongside newer venues

emphasizing artificial intelligence and immersive technologies in learning (e.g., *AI in Education Proceedings, Virtual Learning Environments Conference Series*).

These publication patterns indicate both continuity and diversification: while traditional TEL journals maintain their dominance as core publication outlets, a growing number of conferences and domain-specific journals have become active platforms for disseminating cutting-edge research in AI-assisted learning, gamified instruction, and digital pedagogy innovation.



**Figure 3 Most Relevant Sources**

### 1.2.2 Author Productivity and Influence

Figure 4 presents the *Most Relevant Authors* based on the number of publications indexed in Scopus. The visualization shows a mix of senior researchers with extensive publication records and new entrants contributing to emerging topics such as generative AI in education, learning analytics, and immersive learning environments. Figure 5, depicting *Author Production over Time*, highlights the temporal distribution of author activity. It suggests a sharp increase in publication output in 2021–2022 coinciding with the surge of post-pandemic digital education studies—followed by steady growth through 2023–2024. Authors such as those affiliated with educational technology centers, teacher education institutions, and STEM innovation hubs demonstrate sustained engagement in *TEL* research. This temporal visualization also reveals a pattern of academic maturation within the field: senior contributors maintain a stable output, while early-career scholars show increasing productivity, reflecting new institutional support for EdTech-focused research.

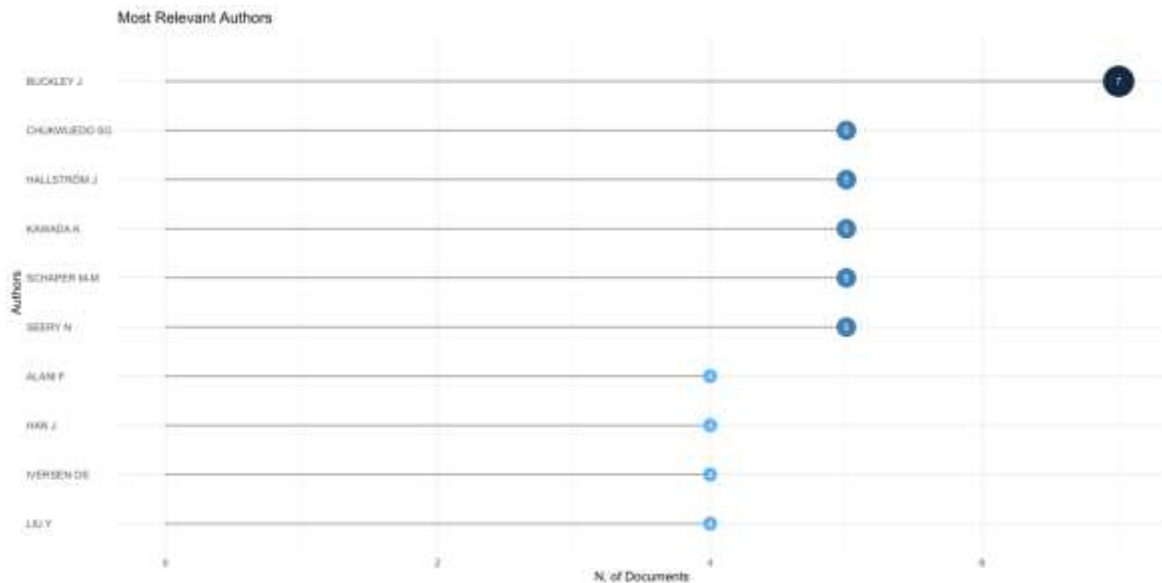


Figure 4 Most Relevant Authors

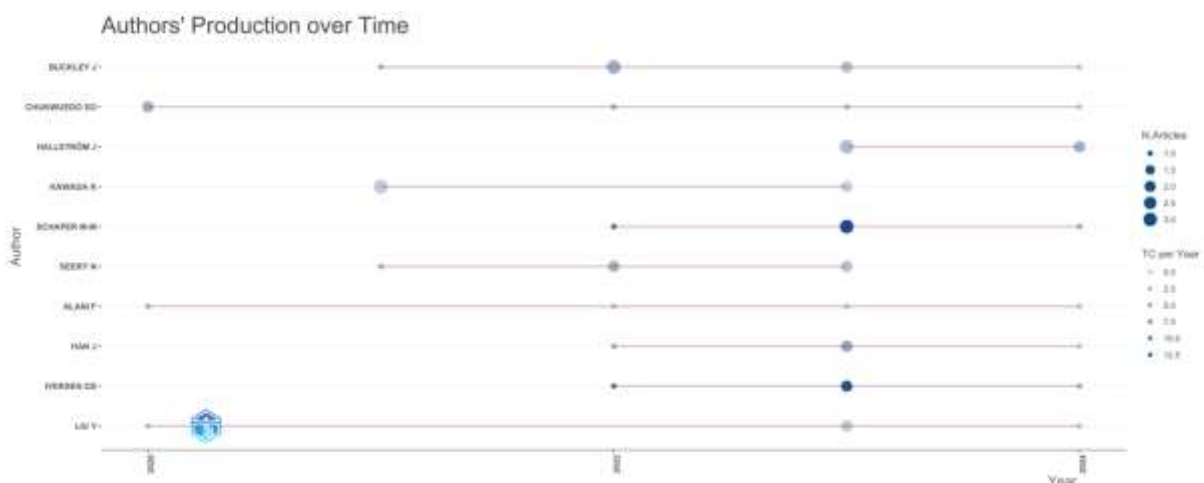


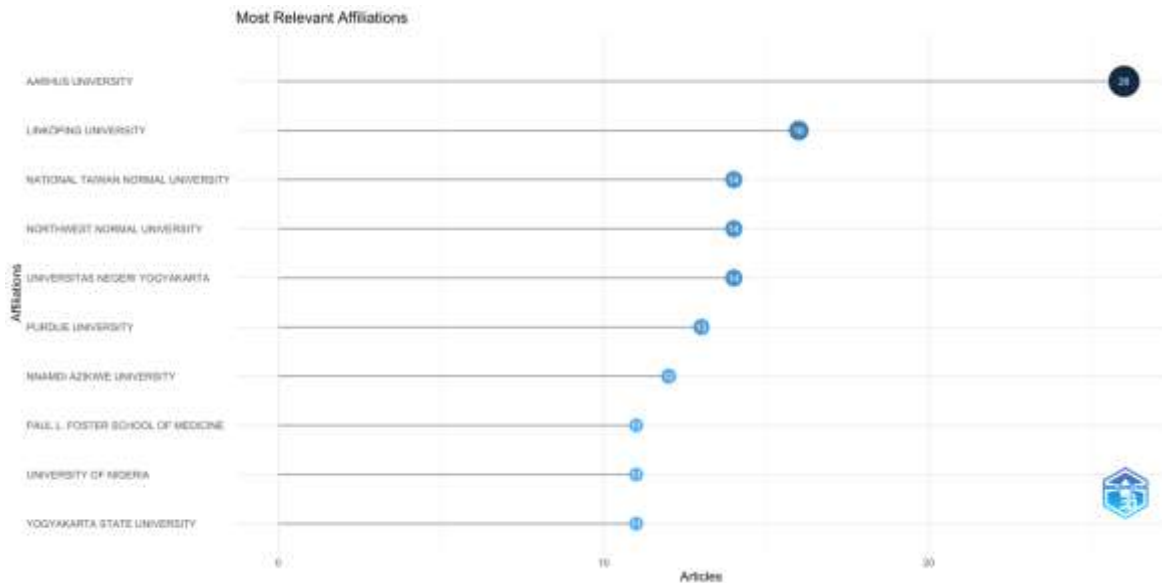
Figure 5 Author Production over Time

### 1.2.3 Institutional, Geographical Distribution and Collaboration

Figure 6 visualizes the *Most Relevant Affiliations*, showing leading universities and research centers that serve as anchors for TEL scholarship. These institutions span Asia, Europe, North America, and Africa, reflecting the global diffusion of TEL research. Notably, universities in countries such as Malaysia, the United Kingdom, the United States, China, and Nigeria appear as recurring centers of activity, each contributing distinctive research agendas – ranging from AI-driven learning systems to inclusive technology education.

Affiliation strings within the dataset show multi-institutional authorship, evidencing collaboration between universities, teacher training colleges, and applied research

labs. Such networks are vital for TEL because they facilitate research-to-practice cycles – bridging innovation, teacher development, and classroom implementation.

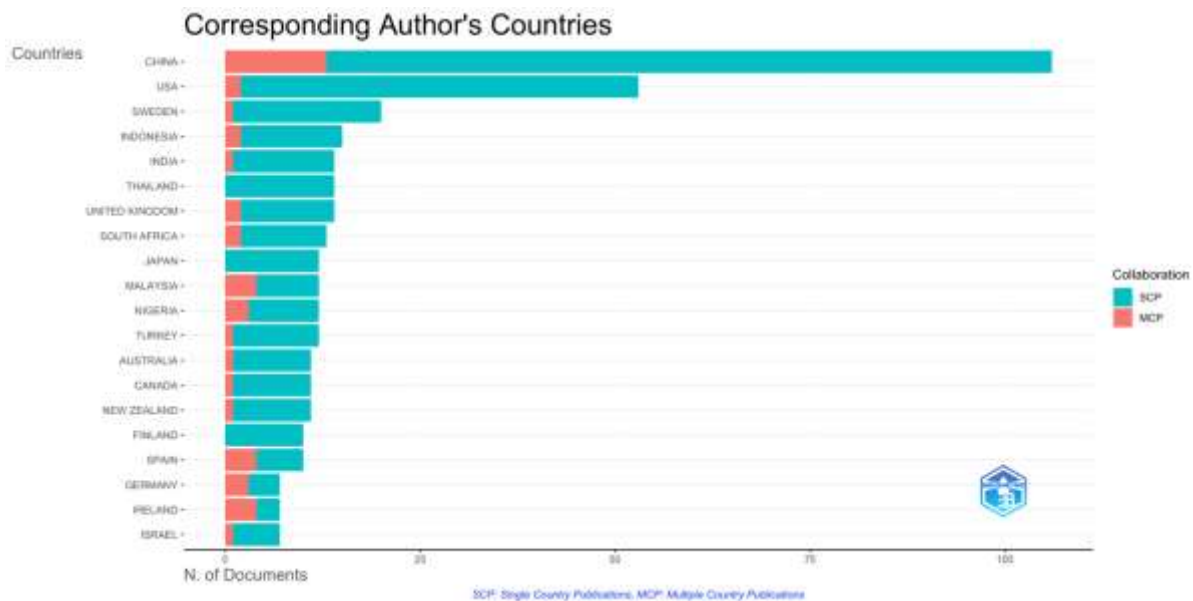


**Figure 6 Most Relevant Affiliations**

The global distribution of affiliations and co-authorship networks reveals a broad, multi-regional pattern of collaboration in research on *Technology in Learning*. The data show that research contributions come from both technologically advanced economies and rapidly developing regions, illustrating that digital transformation in education has become a worldwide agenda.

**Table 1 Top 10 Countries Who Contributed in the Role of Technology in Learning**

No	Country	Documents	Citation	Total Link
1	United States	137	600	25
2	China	37	323	20
3	India	32	157	10
4	Sweden	30	160	15
5	Taiwan	30	242	8
6	Australia	29	212	19
7	Indonesia	29	160	8
8	United Kingdom	24	144	19
9	Malaysia	24	41	10
10	South Africa	24	119	5



**Figure 7 Most Relevant Countries**

The analysis (Table 1 and Figure 8) demonstrates that the United States leads across all three indicators number of publications, total citations, and link-strength confirming its pivotal role in shaping global *TEL*scholarship and collaborative networks. China, India, Sweden, and Taiwan follow as key contributors, reflecting their substantial national investments in digital education and AI-driven learning ecosystems. Australia, the United Kingdom, Malaysia, Indonesia, and South Africa also exhibit active participation, underscoring a distributed global research community rather than one dominated by a single region. The presence of these countries across continents illustrates the post-pandemic expansion of inter-regional partnerships and the strengthening of practice-oriented collaborations among universities, teacher-training institutions, and applied technology laboratories.

### 1.3. Keyword Co-Occurrence and Thematic Structure

To characterize the conceptual landscape with keyword analysis visualized using VOSviewer, revealed seven major thematic clusters, each represented by a distinct color. Cluster 1 is characterized by a red color, Cluster 2 by a green color, while Cluster 3 is distinguished by a blue color. In addition, Cluster 4 is characterized by a yellow color, Cluster 5 has a purple hue, Cluster 6 is distinguished by a light blue shade, and Cluster 7 is distinguished by orange shade. Cluster Each cluster is comprised of interconnected keywords that are visually represented by the same colors. It is important to note that the size and shape of the node are indicative of the frequency of its occurrences. In other words, there is a positive correlation between the size of the node and the frequency of occurrences of these terms. Clustering is employed as a means to gain insights or a comprehensive understanding of bibliometric groupings, whereas image mapping serves the purpose of obtaining a holistic depiction of a bibliometric network.

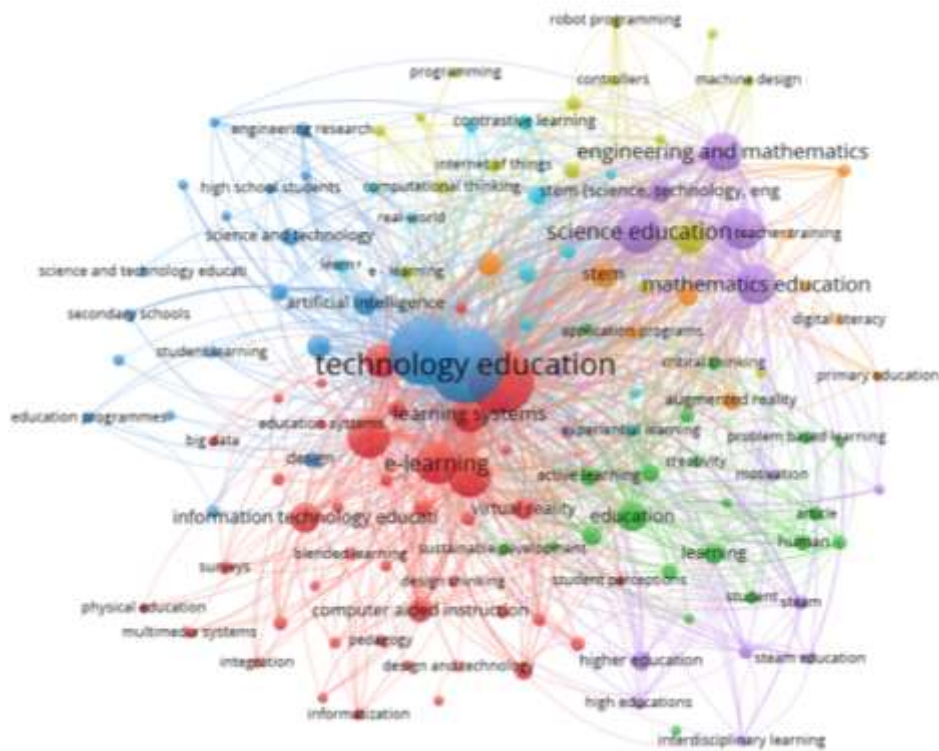


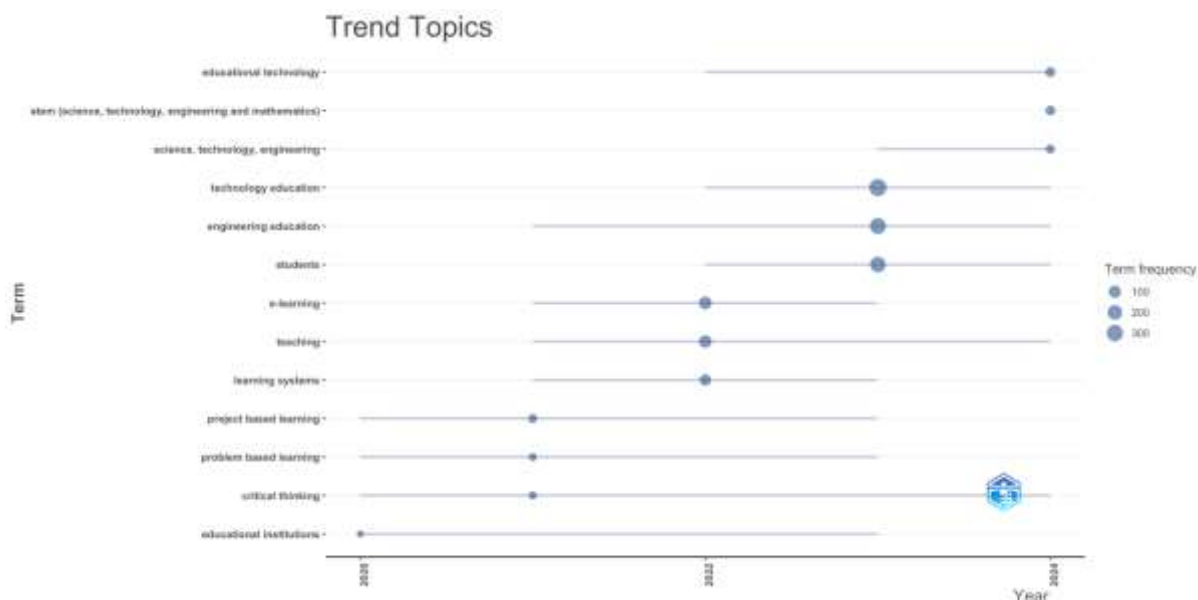
Figure 8 Network Visualisation of the Role Technology in Learning



Figure 9 Tree Map of Authors' Keywords

The tree map displayed in Figure 10 provides a complementary view of keyword prominence and proportional representation within the dataset. Each rectangle corresponds to an author keyword, and its size indicates the frequency of occurrence. Larger tiles, such as *technology education*, *STEM education*, *e-learning*, *artificial intelligence*, and *project-based learning*, dominate the map, reaffirming the results observed in the co-occurrence network. This visual emphasizes that the TEL research community's focus has coalesced around digital pedagogy, AI-assisted learning, and STEM-related competencies, while maintaining interest in teacher education, curriculum innovation, and learning analytics.

Temporal analysis of keyword frequency, illustrated in Figure 11, depicts how research priorities have evolved over the five-year period. The trend topics reveal that e-learning and online education dominated early in 2020–2021 as a direct response to the COVID-19 crisis. From 2022 onward, the focus shifted toward AI in education, learning analytics, virtual reality, and computational thinking, indicating a transition from emergency remote teaching to sustainable innovation in digital learning ecosystems. This progression demonstrates that TEL research has matured from *reactive adoption* to *strategic integration* of technology in pedagogical design. Furthermore, topics such as inclusion, teacher digital competence, and ethical AI began to appear more frequently in 2023–2024, suggesting growing awareness of human-centered and policy-aligned technological implementation.



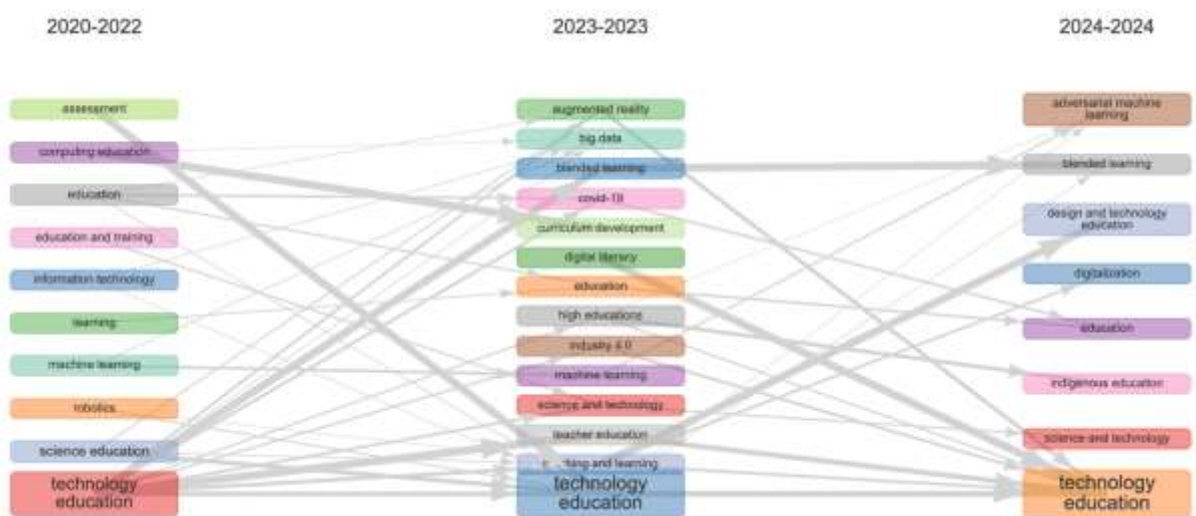
**Figure 10 Trend Topics of Technology in Learning**

The thematic evolution map (Figure 12) visualizes how clusters have merged, branched, or evolved over time. Earlier themes like *online learning* and *digital literacy* have progressively linked with newer constructs such as *AI-assisted learning*, *immersive environments*, and *computational thinking*. This demonstrates a continuous conceptual

expansion—where pedagogical adaptation and emerging technologies converge into more complex, interdisciplinary research frameworks.

In particular, the thematic evolution shows that:

- Digital pedagogy remains the backbone of the field.
- AI and data analytics have become the dominant growth area since 2022.
- Equity and accessibility considerations have entered mainstream TEL discourse, ensuring inclusivity remains integral to technological progress.



**Figure 11 Thematic Evolution of Technology in Learning**

## 2. Discussion

The findings of this bibliometric study reveal that the integration of technology-enhanced learning (TEL) has evolved dynamically between 2020 and 2024, reflecting major shifts in global educational research and practice. These patterns show that TEL has moved beyond simple technology adoption toward a broader redefinition of how learning is structured, how knowledge is co-constructed, and how ethical considerations shape digital learning environments. This evolution directly reinforces the theoretical frameworks outlined in the Introduction. For example, the strong presence of keywords such as *project-based learning*, *collaborative learning*, and *active learning* provides empirical support for constructivist and socio-cultural theories, which emphasize learning as an interactive, socially mediated, and learner-centered process (Noguera, 2022; Rezzadori & Oliveira, 2021). Meanwhile, the shift from automation-driven approaches to human-centered digital ecosystems mirrors the transition from Industry 4.0 to Industry 5.0 in education, where technology is positioned not merely as a driver of efficiency but as a complement to human creativity, empathy, and well-being (Murdan, 2024; H. Lu & He, 2023).

The upward trend in publications drawn from 747 Scopus-indexed documents indicates a strong global response to the disruptions of the COVID-19 pandemic (Damopolii et al., 2021; Diz-Otero et al., 2023). The surge in research output during 2020–2021 confirms that TEL initially played a survival role, supporting instructional continuity during emergency remote teaching. However, as systems recovered, the thematic evolution maps show a clear conceptual shift: research focus moved from crisis-driven online learning toward intentional, sustainable digital pedagogy. This transition signals a maturation of the field; what began as a reactive response has evolved into a deliberate effort to reimagine learning through innovation, inclusivity, and evidence-based design.

The analysis of thematic clusters further clarifies these theoretical alignments. The prominence of clusters related to STEM education, computational thinking, and teacher education demonstrates how TEL increasingly supports active, inquiry-based learning consistent with constructivist frameworks. Simultaneously, clusters focused on collaboration and digital communities illustrate socio-cultural principles by highlighting the role of interaction and shared meaning-making in digital learning environments. The evolution of AI, robotics, VR/AR, and IoT as central research themes reflects the educational impact of Industry 4.0 technologies (L. V. S. da Silva, 2024). At the same time, the emergence of ethical AI, accessibility, and inclusion in recent years signals a growing shift toward Industry 5.0, emphasizing human-centric and value-driven educational technology (Ali et al., 2025; Nguyen Thi Thu et al., 2023). This indicates that future TEL research must balance intelligent automation with ethical responsibility and learner well-being.

The global distribution of research activity highlights notable geographical trends. The dominance of the United States, China, India, Sweden, and Taiwan in publication volume and citation strength suggests that TEL research remains concentrated in technologically advanced regions. However, the increasing participation of Indonesia, Malaysia, South Africa, and other emerging contexts points to a more diverse and pluralistic research ecosystem. This widening distribution supports Murdan's (2024) argument that technology-driven education has become a transnational field, sustained by cross-institutional collaboration and shared global challenges related to access, equity, and digital readiness.

The trend analysis and thematic evolution diagrams provide additional insight into the temporal dynamics of the field. During 2020–2021, dominant themes—*e-learning*, *digital literacy*, and *online education*—were largely shaped by the pandemic context. As systems stabilized, research interest shifted toward advanced domains including *AI in education*, *learning analytics*, and *immersive learning environments*. More recently, the rise of terms such as *ethical AI*, *teacher digital competence*, and *inclusive design* suggests that scholars are increasingly focused on the moral, pedagogical, and social implications of digital transformation. These findings illustrate a critical turn in TEL research—moving from questions of *what* technology can do toward deeper inquiries

into *how* and *why* technology should be integrated responsibly (Kowligi et al., 2020; Morley et al., 2019).

Methodologically, this study demonstrates the value of bibliometric mapping for tracing conceptual structures and intellectual trends in TEL. The use of VOSviewer and Biblioshiny enabled the visualization of co-occurrence networks, citation structures, and thematic progressions. The methodological rigor employed—especially in data cleaning and normalization—supports the reliability of the findings and highlights the potential of bibliometrics as a decision-making tool for educational planning, research capacity building, and knowledge management (Hamid et al., 2022; X. Zhao et al., 2024).

One key limitation of this study is its exclusive reliance on Scopus as the data source. While Scopus offers extensive coverage, it tends to prioritize English-language journals and publications from established publishers and high-income regions. As a result, research outputs from developing countries, non-English publications, or emerging open-access platforms may be underrepresented. This bias may influence the observed patterns of author productivity, institutional dominance, and thematic evolution. Future studies should consider integrating data from Web of Science, Dimensions, or Google Scholar to produce a more comprehensive and globally inclusive bibliometric landscape.

Future research in TEL should pursue several targeted and actionable directions to deepen the insights revealed in this study. First, qualitative investigations are needed to understand how and why educators adopt emerging technologies such as AI-driven analytics, VR/AR, and robotics, particularly through interviews or case studies that illuminate the practical challenges teachers encounter when interpreting learning analytics or using AI tools for personalized instruction. In parallel, empirical studies on ethical and human-centric TEL should explore students' and teachers' perceptions of privacy risks, algorithmic bias, and digital well-being within AI-supported learning environments. Given the geographical disparities identified in this mapping, comparative cross-country research is also essential to examine how national policies, technological infrastructure, and cultural contexts influence TEL adoption and its outcomes. Furthermore, integrating TEL into broader sustainability frameworks represents a promising area for inquiry, especially in understanding how digital learning can support environmental sustainability, institutional resilience, and the achievement of SDG 4. Finally, longitudinal studies are required to trace the evolution of teacher digital competence over time, particularly as educational technologies transition from Industry 4.0 automation toward Industry 5.0 models of human-machine collaboration.

Collectively, these results confirm that TEL has progressed into a stage of maturity where there is a well-rounded focus on technological advancements, changes in teaching methods, and ethical responsibility. The domain is being increasingly viewed

as a socio-technical framework where human engagement and digital resources develop together to promote inclusive, fair, and tailored educational experiences. Instead of focusing solely on the incorporation of tools, modern TEL studies highlight holistic approaches that blend innovation with compassion, data analysis with ethical considerations, and effectiveness with inclusion a change that signifies a major evolution in the principles and practices of education in the digital age.

#### **D. Conclusions**

This study mapped global research trends in Technology-Enhanced Learning (TEL) from 2020 to 2024 using bibliometric analysis of 747 Scopus-indexed publications. The findings reveal a consistent rise in research productivity following the COVID-19 pandemic, reflecting a global transition toward technology-enhanced and hybrid learning ecosystems. Dominant themes such as AI in education, STEM/STEAM integration, digital pedagogy, and technology-supported active learning—demonstrate how TEL has evolved simultaneously as a technological innovation and a pedagogical transformation. The United States led in publication volume, citations, and collaboration strength, followed by China, India, and increasingly active contributors such as Malaysia and Indonesia, indicating a growing internationalization of TEL scholarship. Thematic and keyword evolution further shows a conceptual shift from early emphases on e-learning and digital literacy toward more advanced discussions on AI-driven personalization, learning analytics, accessibility, and ethical inclusion. Beyond mapping research directions, this study offers theoretical implications by showing that TEL trends empirically align with constructivist and socio-cultural learning theories. The prominence of clusters related to collaboration, project-based learning, and active engagement affirms that global TEL research is increasingly grounded in learner-centered and socially situated frameworks. Practically, the findings suggest clear priorities for policymakers and institutions. Policymakers should allocate resources not only for digital infrastructure but also for sustained professional development that strengthens teachers' digital competence and supports the pedagogical integration of emerging technologies. Ethical guidelines and assessment frameworks are needed to ensure fairness, transparency, and data privacy in AI-supported learning systems. Educational institutions should promote interdisciplinary collaboration and develop evidence-based strategies for inclusive access, especially in regions affected by technological disparities. Future research should broaden bibliometric analysis to include databases such as Web of Science or Dimensions for a more comprehensive global perspective. Qualitative and mixed-method studies are also needed to examine how TEL innovations influence teaching practices, learning outcomes, and equity in diverse learning contexts. Overall, this study concludes that TEL represents a transformative movement that integrates technological advancement with empathy, ethics, and inclusive educational values.

## E. Acknowledgement

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