JTPED
Journal of Technological Pedagogy and Educational Development
Vol. 1, No. 2, 2024, pp. 53-66
https://ejournal.jtped.org/ojs/index.php/jtped

Mapping Digital Learning Transformation for 21st Century Skills: A Bibliometric Analysis

Puspa Widyastuti [a,1,*], Mariano Dos Santos [b,2], James Leonard Mwakapemba [c,3]

[a] Universitas Negeri Yogyakarta, Indonesia
[b] Instituto Católico para a Formação de Professores, Baucau, Timor Leste
[c] Institute of Rural Development Planning, Tanzania
[1] puspawidyastuti.2024@student.uny.ac.id; [2] mariano@icfptlmarista.com; [3] jamesleonard866@gmail.com
* Corresponding Author

ARTICLE INFO

Article history
Received July 09, 2025
Revised July 20, 2025
Accepted July 22, 2025

Keywords
Digital transformation;
21st century competencies;
Digital literacy;
Bibliometric analysis

ABSTRACT

Digital transformation in education is key in preparing students to face the challenges of the 21st century, especially in building critical thinking, communication, collaboration, and creativity (4C) skills. The acceleration of technology adoption during the COVID-19 pandemic has also strengthened digital integration in learning, but it has also posed challenges such as access inequalities, pedagogical readiness, and infrastructure gaps. This research aims to map the direction and development of global studies on the transformation of digital learning and competencies in the 21st century using a bibliometric approach. Data were collected from the Scopus database for the 2015–2025 period, with filters for social science subjects, journal article types, English, and open access. Of the initial 418 articles, 71 selected articles were analyzed using Bibliometrix through Biblioshiny. The results show a significant upward trend in publications since 2017, with a peak in 2024. The main themes that emerged included digital literacy, active learning, computational thinking, and higher education. Indonesia and Malaysia became the most dominant countries in publications, indicating the strategic role of the Asian region in the development of this research. The thematic map identifies core themes relevant to technology-based innovative learning. This study provides a comprehensive overview of the scientific landscape in digital education and forms the basis for policy formulation and curriculum design that is more adaptive, inclusive, and future-oriented. The implications of these findings are important for policymakers and curriculum developers to design adaptive and future-oriented digitalization strategies.

1. Introduction

Digital transformation in education is a necessity in the era of technological disruption and the industrial revolution 4.0, which has a major impact on learning patterns around the world. This shift is not only about integrating technological tools in the teaching and learning process, but also touches on a deeper dimension, namely, curriculum changes, pedagogical methods, and competency-oriented assessments in the 21st century [1]. Modern education requires graduates not only to master theoretical knowledge, but also to be able to think critically, creatively, communicatively, and collaboratively. These skills are known as the 4Cs (Critical thinking, communication, collaboration, and creativity) and are the foundation of various 21st-century educational models [2], [3].

https://doi.org/10.59247/jtped.v1i2.14

Project-based learning and cross-disciplinary approaches have also been shown to increase the relevance of education to real-world needs [4]. This transformation is accelerated by external conditions such as the COVID-19 pandemic, which forces educational institutions to switch to online learning en masse and opens up opportunities for the exploration of new technologies such as AI, machine learning, and big data in the learning system [5], [6], [7]. However, these changes present real challenges in the form of access gaps, pedagogical limitations, and digital infrastructure readiness in various educational contexts [8]. There are still many educators who do not have the pedagogical readiness to adopt technology in learning. Studies in Ethiopia reveal that lecturers in various universities have not fully mastered the principles of digital pedagogy necessary to prepare for 21st-century competencies [9]. In Indonesia, the employability of vocational students is also greatly influenced by internship experience and mastery of 21st-century skills obtained through an experiential learning approach [10]. Changes in the education system also have an impact on the way teachers design and deliver learning materials. Teachers' digital skills should be accompanied by sensitivity to learners' social and cultural contexts, and digital-based strategies should be integrated with collaborative learning models to increase student ownership [11], [12]. In addition, a curriculum based on digital literacy is also important to strengthen social-emotional and critical thinking skills. In line with values-based approaches and cultural identity, students can shape students' digital literacy patterns in a more contextual manner [13].

Digital platforms based on mobile learning and AI are used to encourage reflective practice in students [14], included in the realm of accounting and finance learning [15]. It also emphasizes the importance of strengthening the support ecosystem for teachers in integrating technology into daily teaching. Students' digital competence is highly dependent on access, cultural context, and community support, such as technology-based mathematics education [12]. Gamification and AI-based learning have also been proven to increase student learning motivation and engagement, both in formal and external learning [16], [17]. The SECI model has also been widely used in transforming learning practices [12]. Teachers' digital identities, relationships between schools and families, and digital cultural awareness are important parts of the development of the digital education ecosystem [18], [19], [20]. However, low digital literacy is still a major challenge in various developing countries [21], [22]. Some countries, such as China, have led cross-sectoral integration between universities, industry, and government to build digital learning systems that are sustainable and adaptive to changing times [23]. These phenomena show the complexity and dynamics of digital learning transformation in various parts of the world, so a comprehensive and data-driven analytical approach is needed to systematically understand the direction, tendencies, and contributions of science. However, most of the previous studies are still partial and have not provided a comprehensive mapping of the scientific dynamics in this field. Therefore, the identification of literature gaps is important to produce a more systematic and structured picture. Although the issue of digital transformation in education has been widely studied, most of the research is descriptive or case studies that focus on a specific context or approach. No comprehensive bibliometric study has been found that systematically maps the development of the global literature on the integration of digital learning and 21st-century competencies in the past decade.

In this context, the bibliometric approach is a very relevant strategic tool for mapping the scientific landscape in the field of digital learning transformation [24], [25]. Bibliometrics is a quantitative method used to analyze scientific publications based on metadata such as the number of citations, authors, keywords, institutions, and collaboration networks. Through visualizations such as co-authorship, co-citation, keyword co-occurrence, and bibliographic coupling, this approach allows researchers to identify dominant topics, influential researchers, and research gaps that have not been widely explored. The period of the last ten years or a decade was chosen because it reflects the most dynamic period in the development of digital learning, especially since the great acceleration triggered by the COVID-19 pandemic. By utilizing the Scopus database comprehensively, this study aims to present a scientific map that describes the direction, focus, and development of digital transformation research in education, especially in the context of strengthening competencies in the 21st century. Thus, this study not only makes an academic contribution to the understanding of the evolution of digital learning but also becomes a strategic basis for policy formulation and the development of

adaptive, inclusive, and sustainable educational practices in the digital era. The findings in this study are expected to make practical contributions to education policymakers, curriculum developers, and higher education institutions in designing a more contextual, sustainable, and knowledge-oriented learning digitalization strategy to strengthen 21st-century competencies. In addition, the results of this bibliometric mapping can also be a starting point for further research that explores the integration of technology in learning in more depth, both in terms of pedagogy, policy, and equal access.

2. Method

This study uses a bibliometric approach to analyze the trend of digital learning transformation in the context of 21st-century competencies, based on data from the Scopus database during the period 2015-2025. Search strategy using strings: TITLE-ABS-KEY (("digital education" or "digital learning" or future competencies ") and (" 21st century skills' or "twenty-first century skills" or "competencies of the 21st century" or "future skills" or "future competencies")) AND PUBYEAR > 2014 AND PUBYEAR < 2026 AND (LIMIT-TO (SUBJAREA , "SOCI")) AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (SRCTYPE , "j")) AND (LIMIT-TO (LANGUAGE , "English")) AND (LIMIT-TO (OA , "all")), with social science subject filters (SOCI), journal article document types (ar), English, and open access (OA: all). Of the 418 initial documents, 71 articles were selected after a gradual selection process according to inclusion and exclusion criteria. The analysis was conducted using the Bibliometrix package in the R language of Biblioshiny visual interface that allows descriptive and visual analysis of publication metadata, including mapping of author collaboration networks, keyword occurrence, and evolution of research themes. The article filtering process follows the PRISMA workflow, as shown in Fig. 1, which includes four main stages, namely identification, initial screening, advanced screening, and final inclusion. This approach refers to similar practices used in previous studies by [26], [27], [28], [29], [30], which shows that this method is effective for mapping the dynamics, collaboration, and scientific direction in the field of digital education and future competencies. The explanation is as follows:

2.1. Identification

The identification stage is the first step in the process of selecting documents used for bibliometrics. At this stage, a systematic literature search was carried out using the Scopus database with specific search strings that combined keywords such as "digital education", "digital learning", and "21st century skills". The strings are focused on title, abstract, and keyword fields (TITLE-ABS-KEY) with a publication period limited to 2015 to 2025. In addition, an additional filter is applied to filter only documents within the subject: Social Sciences (SOCI), document type: article (Ar), journal source: journal (j) that are retained. The selection of social science subjects is carried out because the topic of digital education is closely related to pedagogical and social aspects. From this process, 418 documents were obtained through the initial search, and as many as 270 articles were excluded because they did not meet these criteria. Thus, 148 articles remain to be included in the next screening process.

2.2. Screening

At this screening stage, 418 documents that had been collected were then screened based on initial eligibility criteria. Documents that are not included in the category of journal articles or are not published by scientific journal sources are included in the dataset. However, based on the results of the selection, no documents have been eliminated at this stage. So that 148 documents have passed the identification process to the next stage.

2.3. Eligibility

The eligibility stage is a follow-up evaluation process for 148 articles that have passed the initial screening stage. At this stage, two additional exclusion criteria are applied, namely publication language and accessibility. Articles that are not written in English, as well as swords that fall under the open-access category, are eliminated from the dataset. A total of 77 articles were issued at this stage for not meeting the criteria. The selection of articles in English is carried out because this

language is an international scientific communication standard, thus facilitating validation and knowledge exchange globally. Meanwhile, open-access articles were selected to ensure data openness, increase transparency, and facilitate replication and accountability of research results by the broader scientific community. Thus, only 71 articles met all the eligibility criteria and were used in this bibliometric analysis.

2.4. Included

The final stage is inclusion, which is the determination of final documents that are worthy of analysis in this study. A total of 71 articles that met all selection criteria were analyzed using the Bibliometrix package on the R software with the Biblioshiny visual interface. Analysis was carried out on various aspects of publications, including general information (main information), number of annual scientific production (annual scientific production), most relevant journal sources (most relevant sources), most relevant authors (most relevant authors), leading affiliated institutions (most relevant affiliations), and countries contributing main publications (most relevant countries and countries' scientific production). In addition, the analysis also includes thematic maps and the most relevant words. All of these processes follow the PRISMA framework to ensure scientific validity, transparency, and replication of methods.

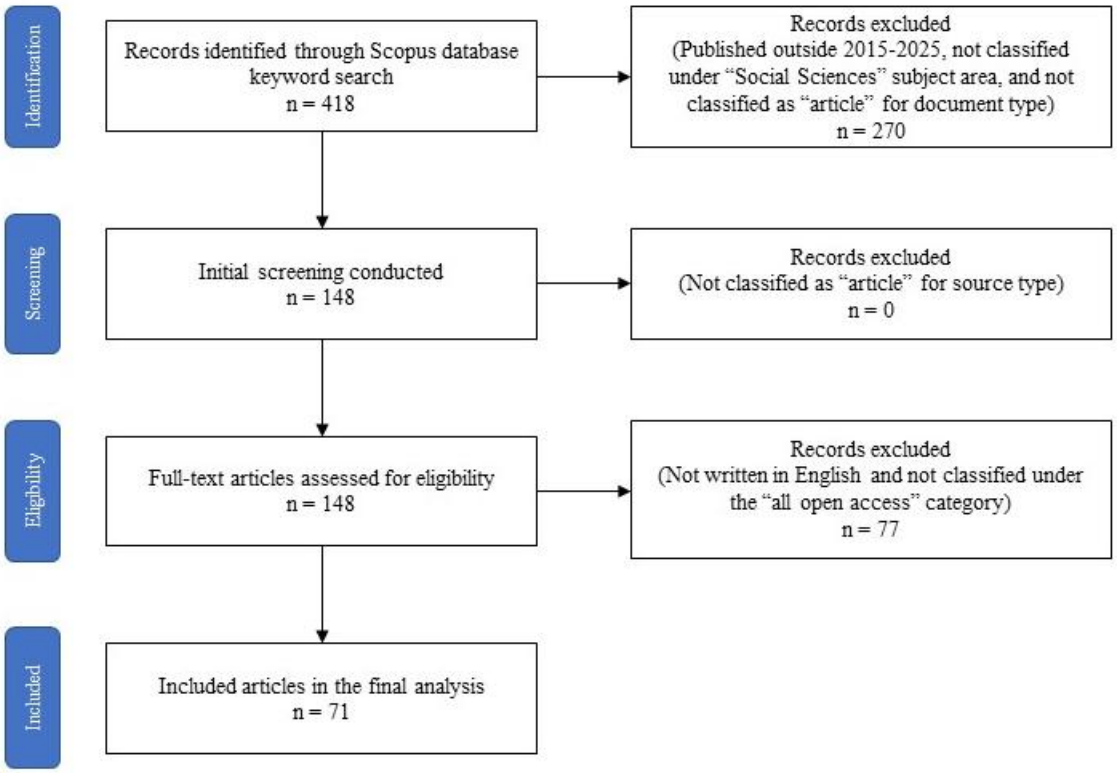

Fig. 1. Prisma Flow Diagram Article Selection Process

3. Results and Discussion

3.1. Main Information

Bibliometric analysis of 71 documents obtained from the Scopus database yielded some general information that can be seen in Fig. 2. The publications analyzed covered a period between 2017 to 2025, although the initial search range was set from 2015 to 2025. This shows that articles that meet all selection criteria (social science subjects, journal article type, English, and open access) have only begun to appear in relevance since 2017. A total of 71 documents came from 61 different sources (journals) for a total of 241 authors involved. Of all these documents, only 10 documents written by

one author (single-authored) showed the dominance of collaboration in this study. The average number of collaborators per document is 3.42 authors, while the international collaboration rate reaches 18.31% which reflects cross-border involvement in research related to digital learning transformation and 21st-century competencies. In terms of publication growth in this topic shows an annual growth rate of 18.92% which signifies a significant increase in academic interest in the last decade. The total number of keywords used by the authors reaches 304 keywords, reflecting the diversity of focus and topical approaches in this field. In addition, all documents refer to 3685 references with an average age of 2.63 years, which indicates that the literature studied is relatively new and up-to-date. The average citation per document is 17.1, which shows that the documents in this dataset have a fairly high scientific impact in their field. Overall, this information shows that the literature on digital learning transformation and 21st-century competencies is actively developing collaboratively and receiving significant attention from the international scientific community.

Fig. 2. Main Information

3.2. Annual Scientific Production

Fig. 3 shows the annual scientific production trends related to the topic of digital learning transformation and 21st-century competencies during the period 2017 to 2025. There has been a fairly stable increase from year to year, starting from only 1 publication in 2017, increasing slowly until reaching its peak in 2024 with a total of about 25 articles. After 2021, the number of articles was relatively stable, then experienced a significant surge in 2023 and 2024. This peak in productivity shows the increasing academic attention to this topic, especially after the pandemic, which accelerated the adoption of technology in education. However, in 2025, there will be a drastic decrease in the number of publications, which may be due to limited publication time, an indexing process that has not been completed, or articles that are still in the publishing stage, as also observed in bibliometric trends [28]. This growth trend is in line with the findings [25], which also reported a surge in publications in the field of digital education in the post-pandemic period. The implications of this trend suggest that policymakers and educational institutions need to capitalize on the growth momentum of research to formulate more adaptive digital learning transformation policies and support the strengthening of 21st-century skills at various levels of education. Overall, this trend reinforces the previous results that the literature in this field shows active growth with an annual growth rate of 18.92% as reflected in the analysis of key information.

3.3. Most Relevant Sources

Fig. 4 shows the sources or journals that published the most articles related to digital learning transformation and 21st-century competencies during the analysis period. The most dominant journal is Education Sciences, with a total of 5 publications. Followed by the Journal of Ecohumanism and Sustainability (Switzerland), which each contributed 3 articles. Furthermore, the International Journal of Emerging Technologies in Learning and Sustainability (Switzerland) also stood out with 2 publications each. Some other journals that contributed with 1 article include Advances in Medical Education and Practice, Advances in Physiology Education, Asia Pacific Journal of Education, and

Bordon. Revista de Pedagogia and Horizon Education. This distribution shows that the topic of digital learning and 21st-century competencies has received attention from various multidisciplinary journals, both in the fields of education, technology, and health. This diversity of sources also reflects the breadth of scope and approach in the studies conducted.

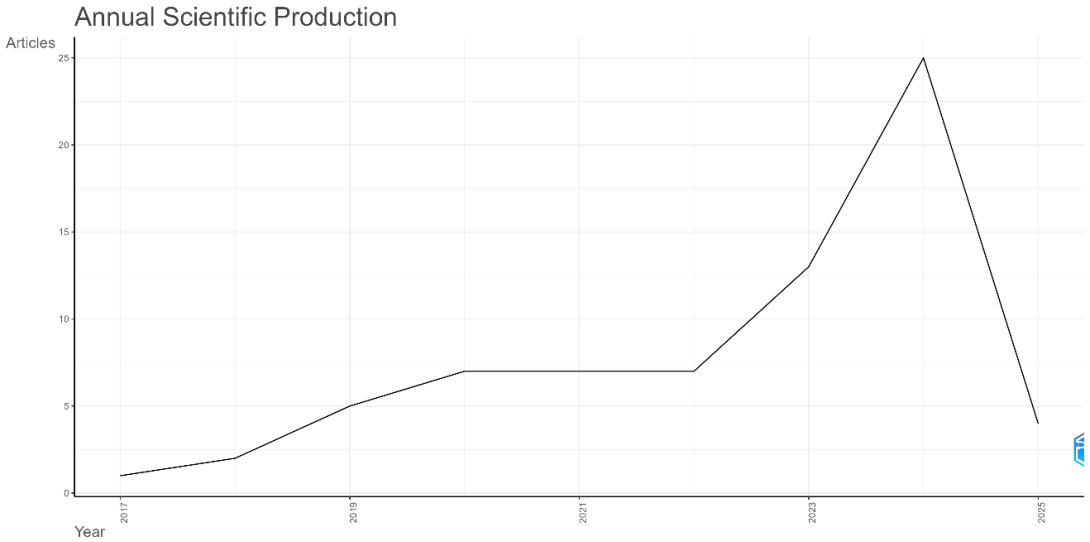

Fig. 3. Annual Scientific Production

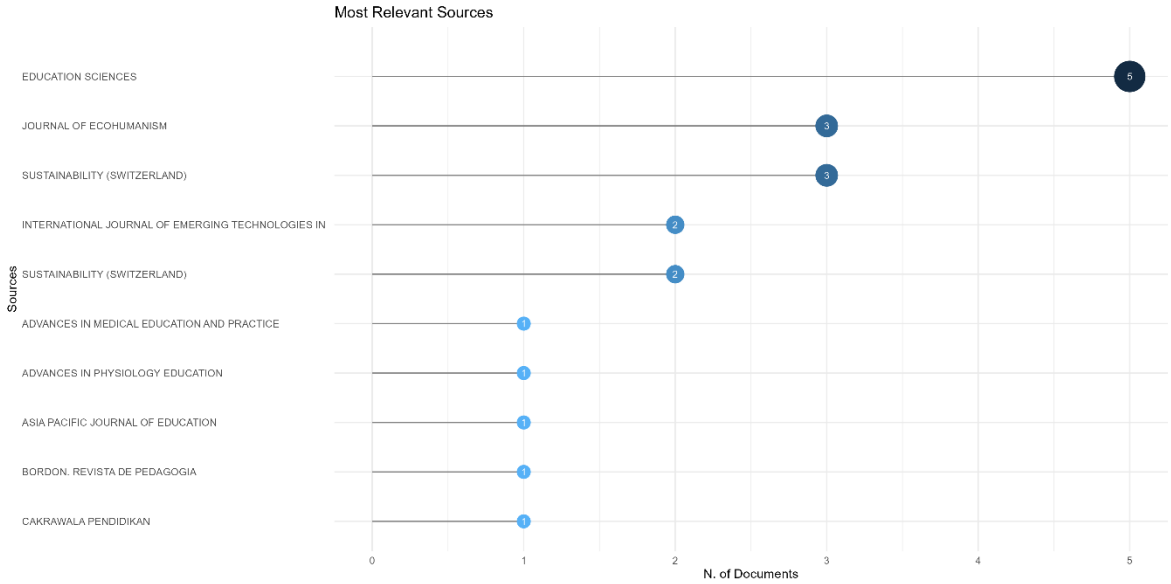

Fig. 4. Most Relevant Sources

3.4. Most Relevant Authors

Fig. 5 shows the most prolific authors in publications on digital learning transformation and 21st-century competencies. The author with the highest number of publications is Ramírez-Montoya, MS, with a total of 3 documents. Meanwhile, there are ten other authors who each contributed 1 article, including Abina A, Agbo FJ, Akcaalan M, Akhyar M, Al-Atabi M, Alali R, Alcantar-Nieblas C, Alfaro-Ponce B, and Ali MH. These findings suggest that contributions in this field are scattered among many researchers, with a relatively small dominance of a single individual, except Ramírez-Montoya, who seems consistent in developing this topic in some of his scientific works. This reflects the character of the field of study that is still wide open with collaboration across diverse researchers and institutions.

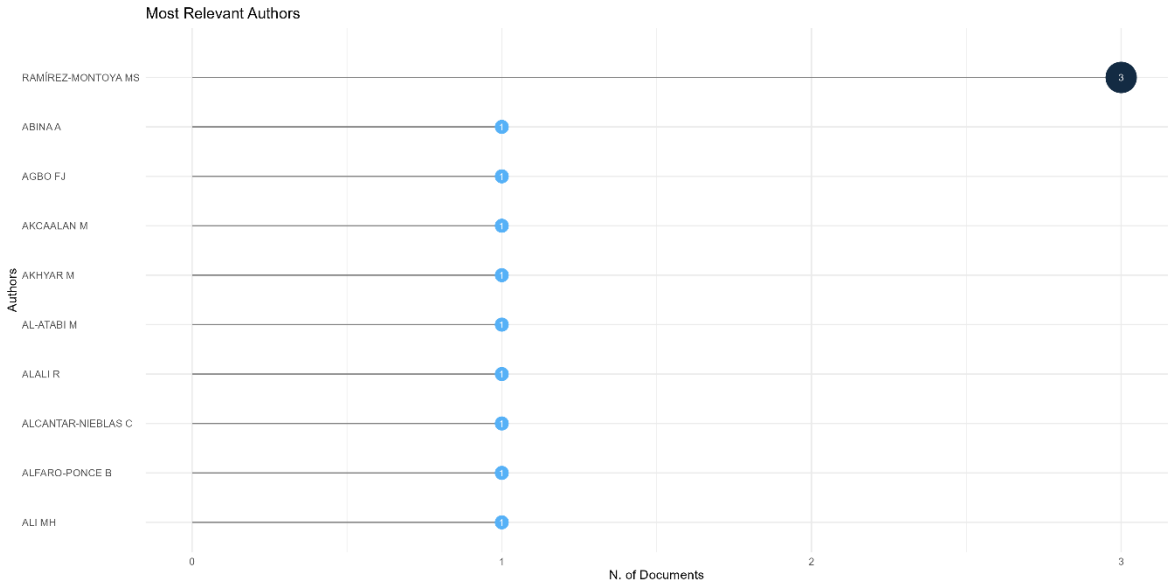

Fig. 5. Most Relevant Authors

3.5. Most Relevant Affiliations

Fig. 6 shows the affiliated institutions that contribute the most to scientific publications related to the transformation of digital learning and 21st-century competencies. Heriot-Watt University Malaysia is the most dominant institution with a total of 9 publications. Followed by the National University of Malaysia and the University of Helsinki, which each contributed 7 articles. Kamianets-Podilskyi Ivan Ohienko National University is in the next position with 6 publications. In addition, Pavlodar Pedagogical University, Universitas Pendidikan Indonesia, and Universiti Putra Malaysia each contributed 5 publications. Meanwhile, Eastern Mediterranean University, Flame University, and the School of Engineering and Sciences each contributed 4 articles. These findings show that the contribution of research in this field is fairly evenly distributed in various countries, especially in Asia and Europe, and reflects the strong role of higher education institutions in supporting the development of studies on the digitalization of learning and competencies in the 21st century.

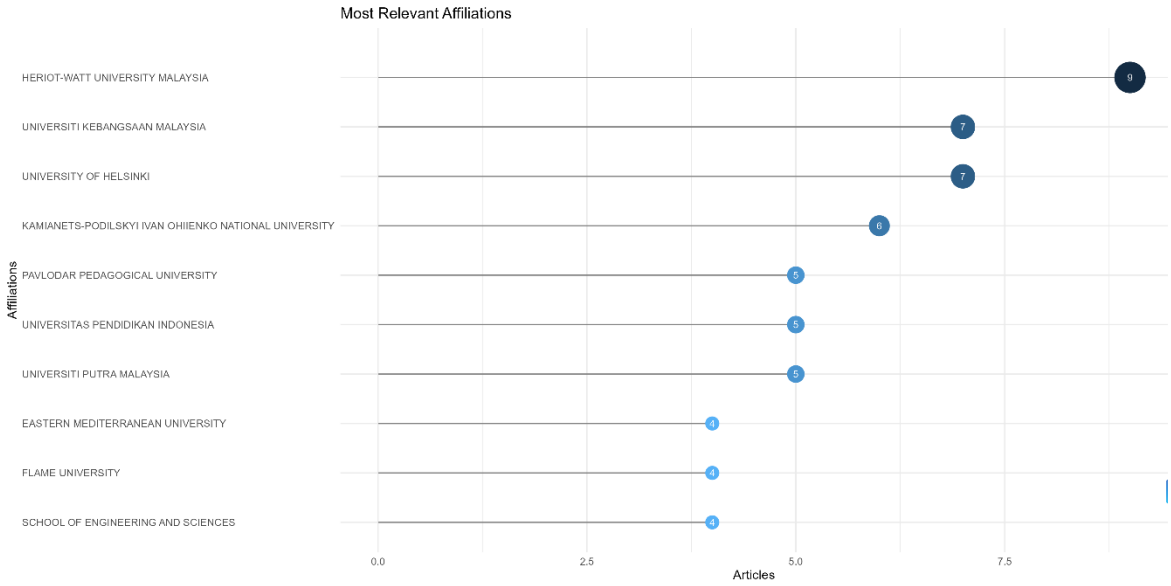

Fig. 6. Most Relevant Affiliations

3.6. Most Relevant Countries

Fig. 7 shows the distribution of the corresponding authors' countries of origin in publications related to the transformation of digital learning and 21st-century competencies. Indonesia and Malaysia are recorded as the countries with the highest number of publications, each contributing 5 documents. These two countries show a combination of single-country publications (SCPs) and collaborative publications between countries (MCPs). Other countries that are also quite active are Spain, Finland, and South Africa, with 4 documents each, all of which are single-country publications. The United States and Mexico also contributed 3 documents, in which the United States was more prominent in international collaboration. Meanwhile, Australia, China, Colombia, and Hungary contributed 2 documents each, followed by several other countries such as Austria, Canada, the Czech Republic, Egypt, Estonia, Hong Kong, India, and Israel with 1 document. This data shows that the topic of digital learning and 21st century competencies is attracting global attention with a pattern of collaboration that varies between countries, both in the form of domestic and international research.

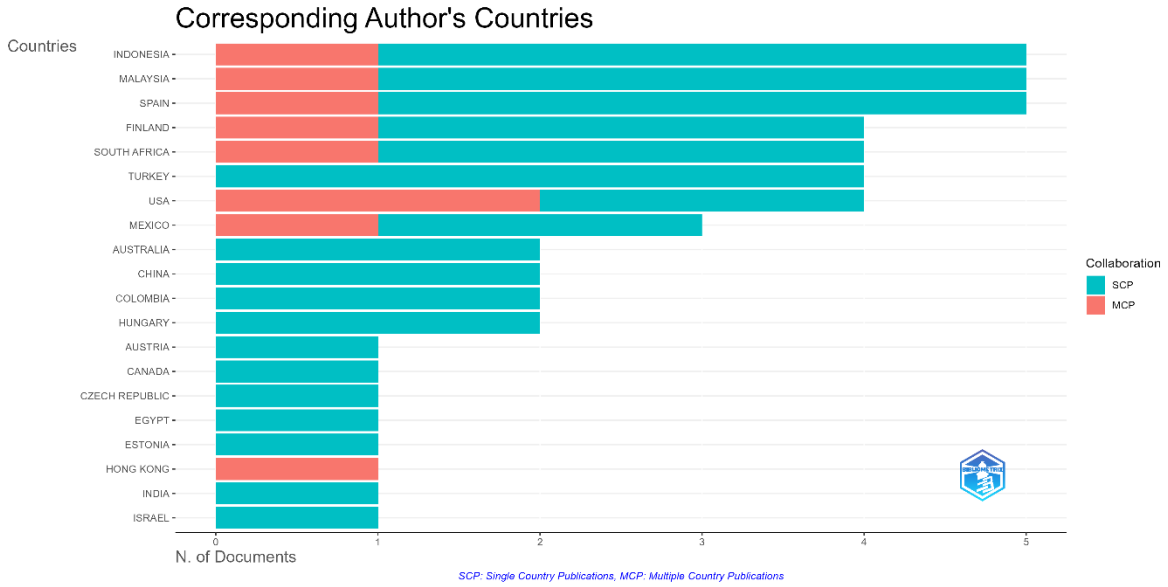

Fig. 7. Most Relevant Countries

3.7. Countries' Scientific Production

Table 1 presents the top ten countries based on the frequency of appearances in the publications analyzed. Indonesia occupies the top position with a total of 32 appearances, followed by Malaysia 22 times. Turkey and Spain also showed quite significant contributions with 19 and 18 appearances, respectively. The United States was recorded 15 times, while Ukraine and Mexico appeared in 13 and 11 publications, respectively. Finland, South Africa, and Colombia complete the list with frequencies between 7 to 10. This data reflects that the Asian region has a strong dominance in publications related to digital learning transformation and 21st-century competencies, followed by several countries from Europe and the Americas. The high frequency also shows the active role of institutions and researchers from these countries in developing technology-based educational studies and innovations.

3.8. Thematic Map

Fig. 8 shows a thematic map that illustrates the distribution and relationships between themes in publications related to digital learning transformation and 21st-century competencies. The upper right quadrant (motor themes) includes themes with a high level of density and centrality, such as critical thinking, active learning, digital literacy, computational thinking, higher education, and 21st century skills that are central to research development and have strong connectivity with other themes. The top left quadrant (niche themes) contains themes such as future skills and pre-service teachers who develop independently but are less central in the main network. The lower right quadrant (basic themes) is filled with themes that are broadly relevant but still low in development, such as teacher

education and engineering education. The lower left quadrant (emerging or declining themes) displays themes that are still in the early stages or starting to be abandoned, such as entrepreneurship education, teaching and learning, and self-efficacy. This map shows that current research tends to focus on strengthening 21st-century skills that are closely related to digital learning innovations and active approaches in higher education.

Table 1. Countries' Scientific Production

Country	Frequency
Indonesia	32
Malaysia	22
Turkey	19
Spain	18
USA	15
Ukraine	13
Mexico	11
Finland	10
South Africa	9
Colombia	7

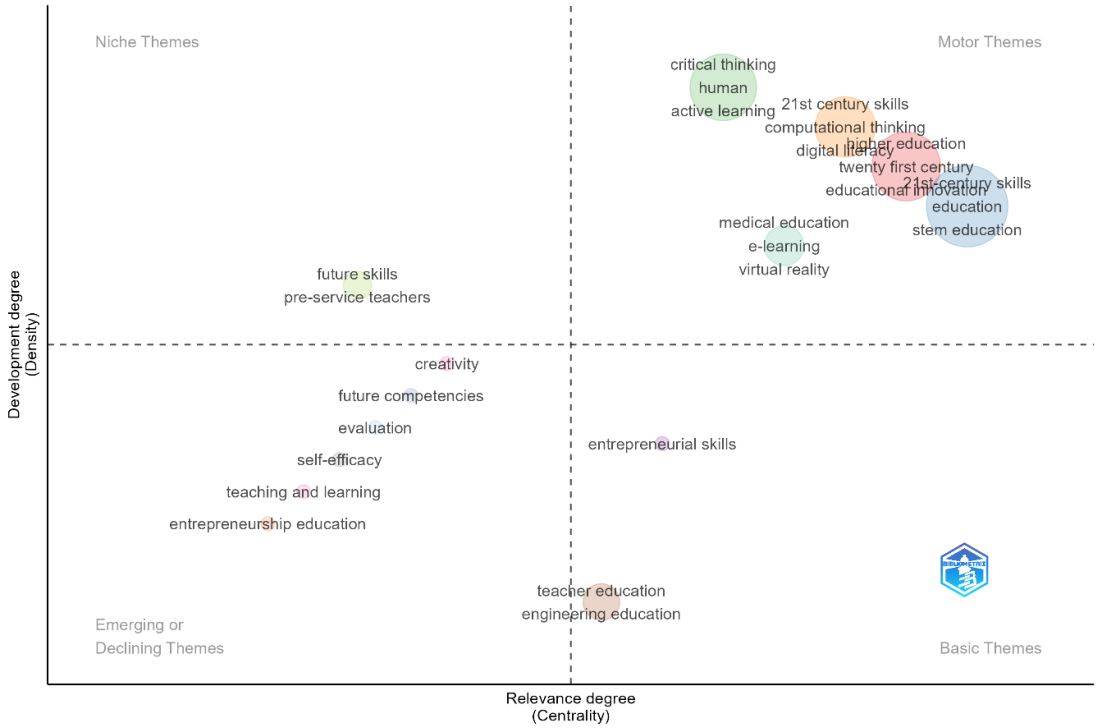

Fig. 8. Thematic Map

3.9. Most Relevant Words

Fig. 9 shows the most frequently appearing keywords in publications related to digital learning transformation and 21st-century competencies. The most dominant keyword was higher education, with 9 appearances, followed by 21st-century skills and education, 6 times each. The theme of STEM education also stands out with a frequency of 5 times. Some other keywords that also appear quite often are curricula, project-based learning, sustainable development, teacher education, and twenty-first century which each has 4 appearances. The phrase 21st century skills in the form of writing without hyphens appears 3 times. This distribution shows that the focus of research in the last decade has been strongly related to higher education, 21st-century skills development, and contextual learning approaches such as project-based learning and sustainable development. This diversity of keywords

reflects the breadth of approaches used in responding to the challenges of digital learning transformation in various educational contexts.

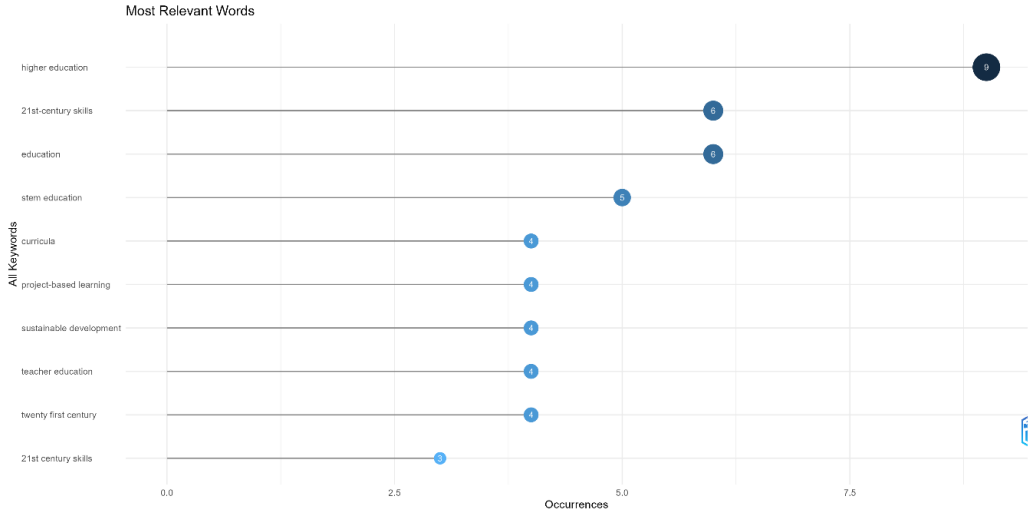

Fig. 9. Most Relevant Word

3.10. Discussion

The transformation of digital learning in preparing 21st-century competencies is a response to fundamental changes in the world of education due to technological disruption. These changes not only touch on technological aspects but also affect curriculum design, teaching methods, and assessment strategies oriented towards the development of the 4 C's: critical thinking, communication, collaboration, and creativity skills. Project-based learning and cross-disciplinary approaches are becoming increasingly relevant because they can bridge the gap between theory and practice [15]. In line with [5], emphasizes that the integration of digital technology into the curriculum provides opportunities to strengthen contextual experiential learning as well as expand space for exploration of creativity and collaboration in the work environment.

The study uses bibliometric methods to analyze trends and patterns of scientific publications over the period 2015 to 2025. Through the use of Bibliometrix and the Biblioshiny interface, the study managed to map the scientific structure of 71 selected documents systematically curated from the Scopus database. This method refers to similar practices in studies [25], that demonstrate the effectiveness of bibliometrics in mapping the scientific ecosystem and the dynamics of digital transformation in the realm of education. In line with the approach [28], [29], the results of this analysis show a collaborative landscape of authors, dominant institutions, and the most active countries in this field, with Indonesia and Malaysia occupying the top positions. The results show that the scientific literature on this topic has experienced significant growth since 2017, with a surge in numbers in 2023 and 2024. The fairly high average citations per document (17.1) indicates that this topic is of important concern in academic circles. The thematic map shows that concepts such as digital literacy, active learning, and computational thinking are the motor themes that continue to develop. The emphasis on higher education and teacher education is also the basis for strengthening digital literacy and future competencies. This is reinforced by findings [6], which reveals that the integration of technology in higher education requires pedagogical readiness from lecturers as well as a strong institutional support system. These findings also reinforce the global pattern as reported by [29], which emphasizes the importance of digital literacy as a cornerstone of learning innovation. In addition, recent studies also emphasize that digital transformation requires strategic leadership support and adaptive change management systems to bridge challenges across the education sectors [31].

Teachers' digital identities are also an important highlight in this transformation [20], highlighting that the formation of a teacher's digital professional identity is a key element in improving learning design and student agency. On the other hand, low digital literacy and infrastructure gaps are still

major challenges in various developing countries, as reported by a study by [22]. Several studies have also highlighted the importance of developing an integrated digital learning space to support learning across physical and institutional boundaries [31]. This condition underscores the need for strategic policy support and ongoing training programs for educators to minimize competency gaps [7]. In response to such complexity, learning strategies such as gamification and the use of AI are becoming promising alternative approaches, as shown and studies [16], [17]. On increased motivation and student participation through interactive technology-based approaches. In addition, the assessment of digital transformation drivers based on the decision-making framework is also important in universities [31].

By combining a bibliometric quantitative approach and a thematic understanding of the literature, this study manages to present a comprehensive picture of how digital learning transformation has evolved in the last decade. In addition to contributing to the academic foundation, these findings can also be a reference in the formulation of inclusive and sustainable digital education policies, especially in preparing a generation of 21st-century learners who are adaptive and reflective. As a follow-up, future research is also suggested to explore strategic frameworks and models of digital transformation implementation at the higher management level [31], [32], [33] and may expand the focus on new themes such as entrepreneurship education, self-efficacy, and measuring the impact of technology implementation on the context of education in developing countries [26], [27].

4. Conclusion

The results of this study show that digital learning transformation has undergone significant developments in the past decade and has become the center of attention in efforts to prepare competencies for the 21st century. Through a bibliometric approach to 71 scientific articles indexed by Scopus, it was found that themes such as digital literacy, active learning, computational thinking, and higher education dominated scientific discourse. Studies in this field tend to be collaborative across countries and institutions, with the largest contributions coming from Indonesia and Malaysia. In addition, project-based learning methods and the use of technologies such as AI and gamification have proven to be increasingly relevant in strengthening the 4C (critical thinking, communication, collaboration, and creativity) skills in higher education environments. The findings of this analysis indicate that digital literacy not only includes technical aspects but is also closely related to pedagogical design, the formation of educators' professional identities, and adaptive and inclusive digital education policies. On the other hand, barriers such as inequality of access to infrastructure and pedagogical readiness are still major challenges in various contexts of developing countries. The implications of the results of this study can be used as a foothold in the formulation of education policies and the development of a curriculum that is responsive to technological developments and future competency needs. In addition to providing academic contributions, the results of the analysis also open up space for further exploration of themes that are still relatively new, such as entrepreneurship education and self-efficacy in the context of the digitalization of learning.

Declaration

Author Contribution: All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

References

[1] G. P. Mbambo and E. C. du Plessis, “Evaluating technical vocational education and training college student’s digital skills versus throughput rate,” *Discov. Educ.*, vol. 4, no. 1, 2025, https://doi.org/10.1007/s44217-025-00396-8.

[2] C. Martinez, “Developing 21st century teaching skills: A case study of teaching and learning through project-based curriculum,” *Cogent Educ.*, vol. 9, no. 1, 2022,

https://doi.org/10.1080/2331186X.2021.2024936.

[3] P. Singsuriya and L. Rimpeng, "Linking religious literacy to 21st century skills," *J. Beliefs Values*, pp. 1–20, 2025, https://doi.org/10.1080/13617672.2025.2501815.

[4] J. Engelbrecht and M. C. Borba, "Recent developments in using digital technology in mathematics education," *ZDM - Math. Educ.*, vol. 56, no. 2, pp. 281–292, 2024, https://doi.org/10.1007/s11858-023-01530-2.

[5] T. D. Dang, T. T. Phan, T. N. Q. Vu, T. D. La, and V. K. Pham, "Digital competence of lecturers and its impact on student learning value in higher education," *Heliyon*, vol. 10, no. 17, p. e37318, 2024, https://doi.org/10.1016/j.heliyon.2024.e37318.

[6] M. Prosen and S. Ličen, "Evaluating the digital transformation in health sciences education: a thematic analysis of higher education teachers' perspectives," *BMC Med. Educ.*, vol. 25, no. 1, 2025, https://doi.org/10.1186/s12909-025-07420-3.

[7] K. S. Suryanarayana, V. S. P. Kandi, G. Pavani, A. S. Rao, S. Rout, and T. Siva Rama Krishna, "Artificial Intelligence Enhanced Digital Learning for the Sustainability of Education Management System," *J. High Technol. Manag. Res.*, vol. 35, no. 2, p. 100495, 2024, https://doi.org/10.1016/j.hitech.2024.100495.

[8] F. J. Agbo, S. S. Oyelere, J. Suhonen, and M. Tukiainen, "Scientific production and thematic breakthroughs in smart learning environments: a bibliometric analysis," *Smart Learn. Environ.*, vol. 8, no. 1, pp. 1–25, 2021, https://doi.org/10.1186/s40561-020-00145-4.

[9] A. Molla, M. Yayeh, and A. Bisaw, "The current status of faculty members' pedagogical competence in developing 21st century skills at selected universities in Ethiopia," *Cogent Educ.*, vol. 10, no. 2, 2023, https://doi.org/10.1080/2331186X.2023.2228995.

[10] D. Pianda, Hilmiana, S. Widianto, and D. Sartika, "The influence employability of vocational students through internship experiences and 21st-century competencies: a moderated mediation model," *Cogent Educ.*, vol. 12, no. 1, p., 2025, https://doi.org/10.1080/2331186X.2025.2476285.

[11] D. Mhlanga, "Digital transformation of education, the limitations and prospects of introducing the fourth industrial revolution asynchronous online learning in emerging markets," *Discov. Educ.*, vol. 3, no. 1, 2024, https://doi.org/10.1007/s44217-024-00115-9.

[12] D. Żatuchin, "Enhancing knowledge transformation in digital education: an analysis of the SECI model's application in course design and execution," *Discov. Educ.*, vol. 3, no. 1, 2024, https://doi.org/10.1007/s44217-024-00229-0.

[13] H. Benlhabib and A. Berrado, "Towards a digital platform for performance management and systemic improvement of education systems: evidence from Morocco," *Discov. Educ.*, vol. 4, no. 1, 2025, https://doi.org/10.1007/s44217-024-00317-1.

[14] S. H. P. W. Gamage, J. R. Ayres, and M. B. Behrend, "A systematic review on trends in using Moodle for teaching and learning," *Int. J. STEM Educ.*, vol. 9, no. 1, 2022, https://doi.org/10.1186/s40594-021-00323-x.

[15] M. Shin, M. W. Ok, S. Choo, G. Hossain, D. P. Bryant, and E. Kang, "A content analysis of research on technology use for teaching mathematics to students with disabilities : word networks and topic modeling," *Int. J. STEM Educ.*, vol. 10, 2023, https://doi.org/10.1186/s40594-023-00414-x.

[16] J. R. Gómez Niño, L. P. Árias Delgado, A. Chiappe, and E. Ortega González, "Gamifying Learning with AI: A Pathway to 21st-Century Skills," *J. Res. Child. Educ.*, pp. 1–16, 2024, https://doi.org/10.1080/02568543.2024.2421974.

[17] A. R. Carvalho *et al.*, "Developing a gamified digital platform to promote extracurricular activities in basic and secondary schools–preliminary findings," *EMI. Educ. Media Int.*, vol. 61, no. 1–2, pp. 103–116, 2024, https://doi.org/10.1080/09523987.2024.2358651.

[18] B. Vaszkun and K. Mihalkov Szakács, "Looking for student success factors outside of the educators' scope: The effect of digital literacy, personal skills, and learning habits and conditions on self-evaluated online learning effectiveness in management education," *Int. J. Manag. Educ.*, vol. 23, no. 2, 2025, https://doi.org/10.1016/j.ijme.2025.101188.

[19] S. Urbina, M. Ferrer, R. Sofía, and V. Moral, "School - Family Communication in Early Childhood

Education Through Digital Tools," *Int. J. Early Child.*, 2025, https://doi.org/10.1007/s13158-025-00419-3.

[20] I. Engeness, "Developing teachers' digital identity: towards the pedagogic design principles of digital environments to enhance students' learning in the 21st century," *Eur. J. Teach. Educ.*, vol. 44, no. 1, pp. 96–114, 2021, https://doi.org/10.1080/02619768.2020.1849129.

[21] J. Ermeson, S. Carmo, D. Pacheco, C. Orsolin, F. Antonio, and S. Piran, "Digital transformation in the management of higher education institutions," *Sustain. Futur.*, vol. 9, p. 100692, 2025, https://doi.org/10.1016/j.sftr.2025.100692.

[22] S. Babaçoğlu *et al.*, "Promoting benchmarking and best practices in education: An interval-valued spherical fuzzy model for assessing sustainable digital transformation maturity," *Technol. Soc.*, vol. 81, no. February, 2025, https://doi.org/10.1016/j.techsoc.2025.102850.

[23] M. Yang and Z. Shi, "Research on cooperation network and theme evolution of education Digital transformation based on CiteSpace," *Procedia Comput. Sci.*, vol. 242, pp. 729–736, 2024, https://doi.org/10.1016/j.procs.2024.08.154.

[24] E. A. Abou Hashish and H. Alnajjar, "Digital proficiency: assessing knowledge, attitudes, and skills in digital transformation, health literacy, and artificial intelligence among university nursing students," *BMC Med. Educ.*, vol. 24, no. 1, pp. 1–11, 2024, https://doi.org/10.1186/s12909-024-05482-3.

[25] L. I. González-Pérez, J. A. Enciso-González, C. M. Vicario-Solorzano, and M. S. Ramírez-Montoya, "Measuring Digital Transformation in Education 4.0 with DT-Smarty: Valid and Reliable Model," *Technology, Knowledge and Learning*, pp. 1-34, 2025, https://doi.org/10.1007/s10758-025-09844-8.

[26] S. Li, Z. Liu, V. C. Tripathi, and M. A. M. Hashim, "An Investigation of the Landscape of Environmental Education (Ee): A Bibliometric and Systematic Literature Review," *The International Journal of Management Education*, vol. 23, no. 3, 2025, https://doi.org/10.1016/j.ijme.2025.101229.

[27] H. Dissanayake, O. Manta, A. Iddagoda, and M. Palazzo, "Artificial intelligence and management Education: Bibliometric analysis," *Int. J. Manag. Educ.*, vol. 23, no. 3, p. 101222, 2025, https://doi.org/10.1016/j.ijme.2025.101222.

[28] A. Lachheb, J. Leung, V. Abramenka-Lachheb, and R. Sankaranarayanan, "AI in higher education: A bibliometric analysis, synthesis, and a critique of research," *Internet High. Educ.*, vol. 67, p. 101021, 2025, https://doi.org/10.1016/j.iheduc.2025.101021.

[29] B. Zhao and J. Zhou, "Research hotspots and trends in digitalization in higher education: A bibliometric analysis," *Heliyon*, vol. 10, no. 21, p. e39806, 2024, https://doi.org/10.1016/j.heliyon.2024.e39806.

[30] J. C. De Gagne, P. S. Randall, P. D. Koppel, E. Cho, E. R. Blackwood, and H. S. Kang, "Online learning in nursing education: A 21st century bibliometric analysis," *Nurse Educ. Today*, vol. 151, p. 106740, 2025, https://doi.org/10.1016/j.nedt.2025.106740.

[31] A. M. McCarthy, D. Maor, A. McConney, and C. Cavanaugh, "Digital transformation in education: Critical components for leaders of system change," *Soc. Sci. Humanit. Open*, vol. 8, no. 1, p. 100479, 2023, https://doi.org/10.1016/j.ssaho.2023.100479.

[32] K. Wang, B. Li, T. Tian, N. Zakuan, and P. Rani, "Evaluate the drivers for digital transformation in higher education institutions in the era of industry 4.0 based on decision-making method," *J. Innov. Knowl.*, vol. 8, no. 3, p. 100364, 2023, https://doi.org/10.1016/j.jik.2023.100364.

[33] J. E. S. Carmo, D. P. Lacerda, C. O. Klingenberg, and F. A. S. Piran, "Digital transformation in the management of higher education institutions," *Sustain. Futur.*, vol. 9, p. 100692, 2025, https://doi.org/10.1016/j.sftr.2025.100692.