Bibliometrix Analysis of Research on Digitalization and Educational Technology (2017-2024)

Guloyim Rakhimboyeva[1], Alisher Jumanov[1,2], Nigora Nazarova[3], Mohira Sattorova[4] and Shakhnoza Kurbanova[4]

[1]*Tashkent Institute of Irrigation and Agricultural Mechanization Engineers National Research University, Kori Niyoziy Str. 39, 100000 Tashkent, Uzbekistan*

[2]*University of Tashkent for Applied Sciences, Gavhar Str. 1, 100149 Tashkent, Uzbekistan*

[3]*Shahrisabz State Pedagogical Institute, Shahrisabz Str. 10, 181302 Shahrisabz, Uzbekistan*

[4]*University of Information Technology and Management, Beshkent Str. 27, 180212 Karshi, Uzbekistan and Oriental University, Shota Rustaveli Str. 154A, 100121 Tashkent, Uzbekistan*

guloyimraximboyeva5@mail.com, osiyoxonim2025@gmail.com, sattorovamohira@1022gmail.com, shakhnozakurbanova88@gmail.com

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Abstract: Digitalization is becoming a key factor in improving the quality and competitiveness of vocational education, especially in technical universities. It allows for the introduction of modern teaching solutions and supports practical vocational education. This study uses bibliometric analysis to study the dynamics of research related to digital pedagogy and educational technologies. The dataset consists of 93 Scopus indexed publications from 2017 to 2024, which were analyzed using Excel, MapChart and VOSviewer to identify key patterns, influential contributors and new research directions. The results show a significant increase in scientific interest, with the number of publications increasing by more than 65% during the observed period. All reviewed articles were published in English, and the highest contributions came from Germany, the Russian Federation, Finland and China. The analysis shows a clear shift towards technology-enabled learning models that reflect global efforts to modernize vocational education. Thematic trends indicate a strong focus on e-learning ecosystems, the development of digital competencies for teachers, and innovative teaching approaches. Bibliometric mapping highlights active research networks and leading sources that are shaping academic debates on digital transformation. Overall, the findings provide valuable empirical evidence for policy development, strategic planning, and curriculum renewal in vocational education. The study provides historical insights and future-oriented guidance, helping educators, researchers, and decision-makers to promote effective digital transformation in the field.

1 INTRODUCTION

Digitalization is one of the main factors influencing the development of modern vocational and technical education. The rapid development of information and communication technologies has opened up new opportunities. These opportunities help improve the quality and accessibility of education. Digitalization is a much broader concept. This concept introduces innovations to restructure socio-economic sectors around pre-existing digital transformations [1]. Digitization is the act of transforming the digital form created by digitization into meaningful information that can be used to optimize the evolution of society [2].

In many developed countries, digital transformation is closely related to innovative educational models. For example, the “Gifted Student-Teacher Model” in France and the “Merit Program” in the United States were developed by the educational organization P.Debrai - Retzen. In this model, the teacher can arouse interest in the student in his field, teach initiative and broad thinking. The integration of digital tools into education increases the motivation, independence and creativity of students. These efforts will foster digital skills development, job creation, and economic growth in the digital sector [3].

Uzbekistan is implementing large-scale reforms to improve the education system and train highly

qualified specialists [4]. The Ministry of Higher Education, Science and Innovation emphasizes the importance of introducing digital technologies in technical universities. These technologies help to increase the efficiency of teaching and research processes [5]. The National Education Strategy aims to create a digital learning environment. This environment will develop innovation, professional competence and practical skills in students. Digital learning platforms [6] and electronic assessment systems are being gradually introduced. They ensure transparency, flexibility and continuous professional development [7].

Bibliometric analysis is a method used to study scientific publications. It is a quantitative approach that examines data such as the number of articles, citations, and keywords. Unlike traditional reviews, [8] it focuses on objective indicators rather than personal opinions. This method helps to identify research trends and show which topics are developing. It also helps to identify authors, organizations, and countries that are active in a particular field. In recent years, bibliometric analysis has been widely used to study digitalization in education [9]. It shows how research on e-learning, [10] digital pedagogy [11] and professional education has grown over time. Digital pedagogy refers to the use of digital tools to enhance teaching. It helps teachers and students learn more effectively. It increases participation in lessons and gives students different ways to demonstrate their knowledge [12]. Research on open educational platforms by [13] and to digital pedagogy by [14] highlight the growing importance of research in the digital transformation.

The main purpose of this research is to identify pedagogical approaches that improve the digitalization of vocational education through bibliometric analysis. The study also aims to summarize the main scientific contributions, analyze publication trends, and offer recommendations for effective integration of digital technologies in technical higher education institutions. Despite the growing number of studies on educational digitalization, limited attention has been paid to comprehensive bibliometric evaluations integrating publication dynamics, thematic evolution, international collaboration, and digital pedagogy trends within vocational and technical education systems. The novelty of this study lies in the integration of bibliometric mapping, thematic clustering, and international comparative analysis to identify emerging directions in the digital transformation of vocational education systems.

2 MATERIALS AND METHODS

This study analyzed scientific publications on the digitalization of the education system indexed in the Scopus bibliographic database during the period of 2017-2024. The research focused on countries such as Germany, the Russian Federation, Finland, China, the United Kingdom, the United States, Sweden, and Uzbekistan. The bibliometric analysis was conducted in September 2025.

A total of 93 publications related to different countries were selected to identify the main challenges and trends in the digital transformation of education. The data were downloaded in CSV format and processed using Microsoft Excel 2021, RIS format, VOSviewer, and map visualization tools.

2.1 Article Selection and Inclusion Criteria

Articles were retrieved using the keyword “education system,” limited to English-language publications. The inclusion criteria were as follows: document type - “article,” publication period - 2017 to 2024, subject areas - computer science, psychology, engineering, and countries - Germany, the Russian Federation, Finland, China, the United Kingdom, the United States, Sweden, and Uzbekistan. The final selection date was set to September 1, 2025. These criteria ensured the accuracy and consistency of the selected materials for analysis. Research on digital pedagogy and bibliometric trends has demonstrated the growing importance of technology-supported instructional models [14].

2.2 Bibliometric Analysis

Data obtained in CSV format were uploaded to Excel and subsequently subjected to a bibliometric analysis. Prior to analysis, the data were thoroughly checked for completeness and errors. The selected articles were analyzed based on authorship activity, number of publications per year, document types, journals, subject categories, and institutional affiliations.

The most active authors were identified and ranked according to their publication output. For example, Petrov P. was found to be the most productive author with two publications [15]. Furthermore, co-authorship and keyword co-occurrence analyses were performed to reveal the intellectual structure and key thematic areas of research in the field.

2.3 Digitalization-Based Teaching

The analysis emphasized the growing use of digital technologies in teaching practices across different regions. Special attention was given to the development of online learning methods, digital pedagogy, and the enhancement of instructional methodologies through technological integration.

Previous bibliometric studies also emphasized the importance of publication mapping and co-authorship analysis [15]. The bibliographic records were cleaned, normalized, and processed prior to analysis to eliminate duplicate entries and inconsistencies in author names, keywords, and institutional affiliations.

3 RESULTS

As illustrated in Figure 1, the methodological workflow includes data collection, bibliometric filtering, visualization, and thematic interpretation stages.

Early studies focused on industrial digitalization, digital transformation, and multimedia-supported learning environments [16]-[18].

3.1 Trends in Publications on the Methodology and Theory of Teaching

In the context of higher technical education, the implementation of digital technologies plays a crucial role in improving the quality and effectiveness of teaching. Between 2017 and 2024, a total of 93 academic papers were published in different countries focusing on digital transformation in education. The publication trend can be divided into three distinct stages: the introductory stage (2017–2018), the moderate growth stage (2019–2020), and the stable growth stage (2021–2024).

During the introductory stage (2017–2018), five publications were identified, accounting for 5.5% of the total number of papers. Research during this period focused on the application of digital technologies across various domains, providing an overview of emerging socio-technical trends in production [16] and introducing the fundamental concepts of digitalization and digitization [17]. Other studies examined educational technologies, including multimedia content and personalized learning, as well as the use of video-based approaches to improve students' understanding of scientific concepts and communication of scientific knowledge [18].

During the moderate growth stage (2019–2020), the number of publications increased to nine (9.68% of the total), reflecting growing academic interest in digital education. Research highlighted the pedagogical potential of digital technologies for improving teaching quality [19], strategies for developing hybrid campuses during emergency situations [20], the use of ICT in virtual classrooms [21], and the psychological impact of computer use in schools [22]. Additional studies investigated virtual reality as an educational technology [23] and the design of innovative digital learning solutions.

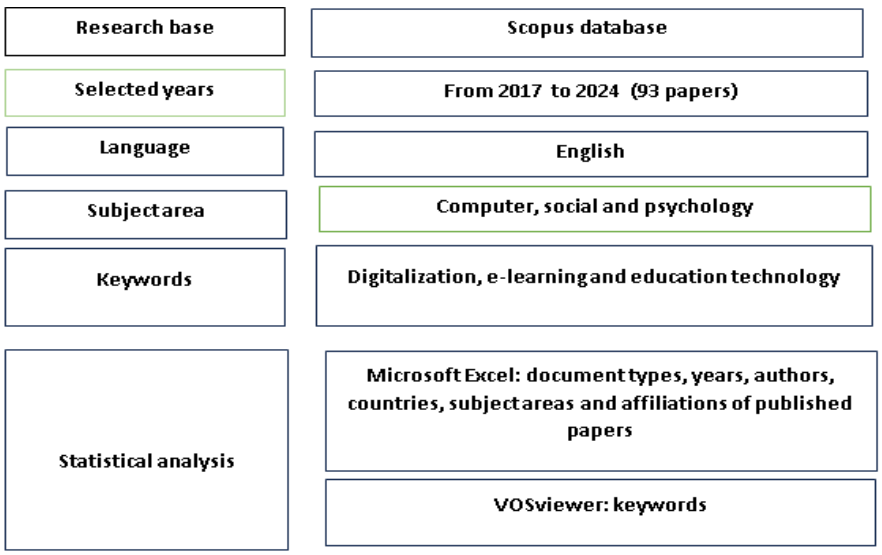

Figure 1: Flowchart of the methodology.

During the stable growth stage (2021–2024), research activity expanded substantially, with 79 publications (approximately 85% of the total). The highest annual output was recorded in 2022 (26 publications), followed by 2021 (21 publications). Studies published during this period focused on online teaching practices in higher education, digital examinations and remote assessment [24], the advantages and challenges of educational digitalization [25], and the influence of teachers' personal characteristics on the effectiveness of remote learning. Other investigations explored the relationship between e-learning and distance education [26], factors facilitating successful digital learning environments, and the application of online educational platforms [27].

Figure 2 demonstrates the annual growth in publications related to educational digitalization between 2017 and 2024.

3.2 Leading Journals in the Field of Educational Digitalization

The bibliometric review identified 88 journals publishing research on digitalization in education across 49 countries. Among them, 13 journals accounted for 42% of all publications. The International Journal of Emerging Technologies in Learning ranked first with seven publications, followed by IFIP Advances in Information and Communication technology (six articles) and IFAC Papersonline (four articles), (Table 1).

Recent publications mainly address online examinations, remote learning efficiency, e-learning systems, and educational platform integration [24]-[27].

Previous international studies also highlighted the growing strategic importance of AI-supported digital pedagogy and adaptive learning ecosystems [28]-[30].

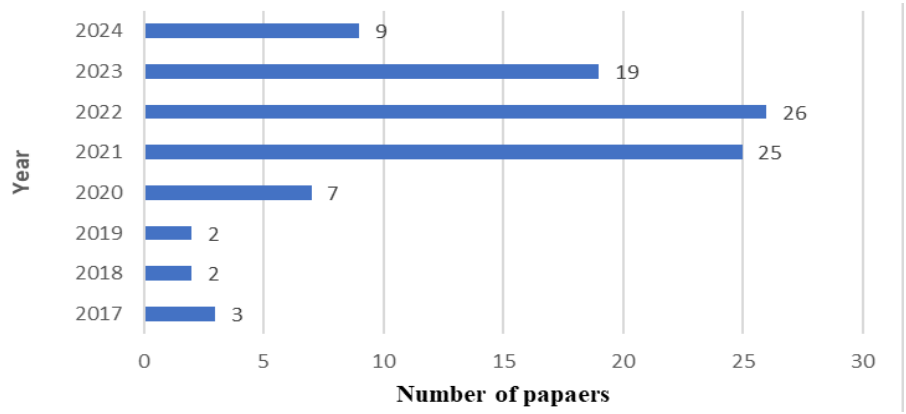

Figure 2: Annual publication output on the digitalization of the education system during 2017-2024.

Table 1: List of journals publishing articles on the digitalization of the education system.

Scopus source title	Number
International Journal of Emerging Technologies in Learning	7
IFIP Advances in Information and Communication Technology	6
IFAC Papersonline	4
Communications in Computer and Information Science	3
Frontiers in Artificial Intelligence and Applications	3
Procedia CIRP	3
Applied Mathematics and Nonlinear Sciences	2
BMC Medical Education	2
Studies in Health Technology and Informatics	2
Sustainability Switzerland	2
Alexandria Engineering Journal	1
Annals of Biomedical Engineering	1
Asian Association of Open Universities Journal	1

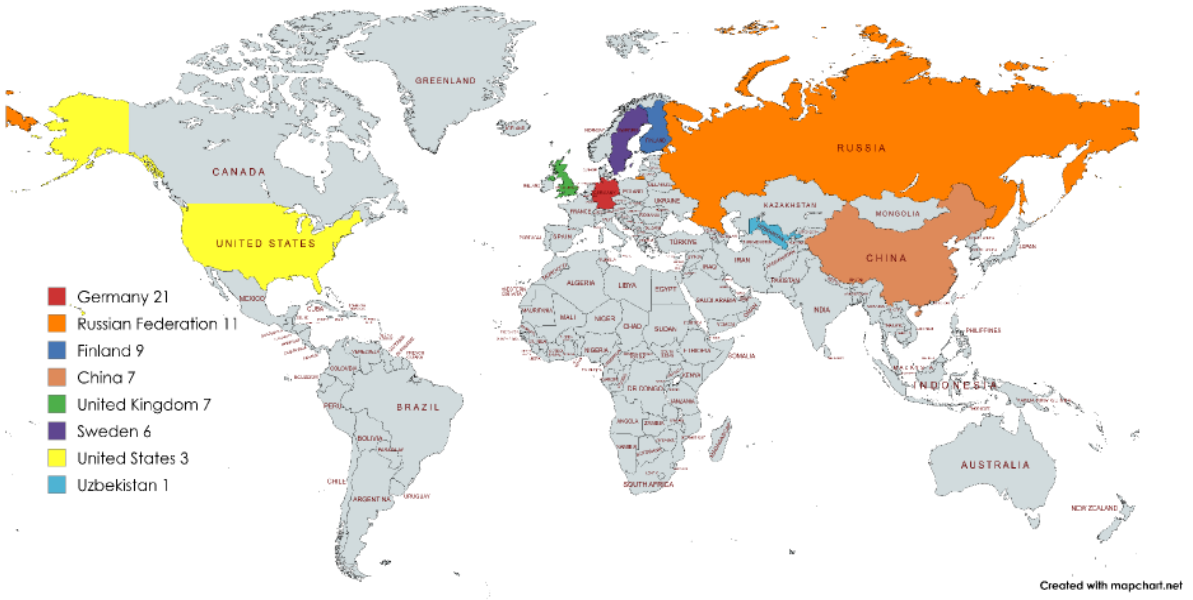

Figure 3: List of leading countries in the digitalization of the education system.

3.3 Country Contributions

In terms of national productivity, Germany led with 21 publications, followed by the Russian Federation (11), Finland (9), China and the United Kingdom (7), Sweden (6), the United States (3) and Uzbekistan contributed one publication during the analyzed period. As shown in Figure 3, Germany, the Russian Federation, Finland, and China were the leading contributors to research on educational digitalization.

3.4 Most Cited Papers

The ten most cited publications focused primarily on the challenges and innovations in online learning and digital transformation in higher education. The leading works included:

- PY - Published year;
- TC - Total citation.

3.5 Most Cited Journals on the Digitalization of the Education System

The effectiveness and impact of publications were analyzed based on the journals in which they appeared. Therefore, this section provides a detailed overview of the most influential journals that have contributed to the study of education system digitalization. The journals with the highest number of publications are summarized in Figure 4, which presents the top-performing sources. Considering this factor, we examined the most prominent journals publishing research on the digitalization of education. Initially, the source titles were organized alphabetically using an Excel dataset containing publications from 2017 to 2024. Subsequently, the total number of citations for each journal was aggregated. Interestingly, this process resulted in an updated list of potential high-impact journals (Table 2).

Among them, the "International Journal of Emerging Technologies in Learning" ranked first in terms of citation count and publication frequency, followed by "IFIP Advances in Information and Communication Technology" and "IFAC Papersonline." These journals demonstrate strong engagement with topics related to digital transformation, educational technologies, and innovation in learning systems.

Figure 4 presents the most influential journals publishing studies on digital transformation in education.

Table 2: List of the most cited publications on the digitalization of the education system.

No	Title	Journal	Corresponding author	PY	TC 2000-2022	Doc.type
1.	Online teaching and learning in higher education: Lessons learned in crisis situations	Computers in Human Behavior	Hofer Sarah Isabelle	2021	181	Article
2.	COVID-19 as an accelerator for digitalization at a German university: Establishing hybrid campuses in times of crisis	Human Behavior and Emerging Technologies	Skulmowski Alexander	2020	153	Article
3.	Machine learning for biochemical engineering: A review	Biochemical Engineering Journal	Mowbray Max. R.	2021	139	Article
4.	Digital transformation readiness in higher education institutions (hei):the case of kosovo	IFAC-PapersOnLine	Limani Ylber	2019	60	Conference paper
5.	COVID-19 impact on teleactivities: Role of built environment and implications for mobility	Transportation Research Part A: Policy and Practice	Mouratidis Kostas.	2022	58	Article
6.	Understanding the challenges of rapid digital transformation: the case of COVID-19 pandemic in higher education	Behaviour and Information Technology	Nurhas Irawan	2022	58	Article
7.	Platform for industrial internet and digital twin focused education, research, and innovation: Ilmatar the overhead crane	IEEE World Forum on Internet of Things	Autiosalo Juuso	2018	52	Conference paper
8.	Data-driven optimization for process systems engineering applications	Chemical Engineering Science	van de Berg Damien	2022	50	Article
9.	Learning experiences from digital laboratory safety training	Education for Chemical Engineers	Viitaharju Panu	2021	39	Article
10.	Digital supply chain surveillance using artificial intelligence: definitions, opportunities and risks	International Journal of Production Research	Brintrup Alexandra Melike	2024	33	Article

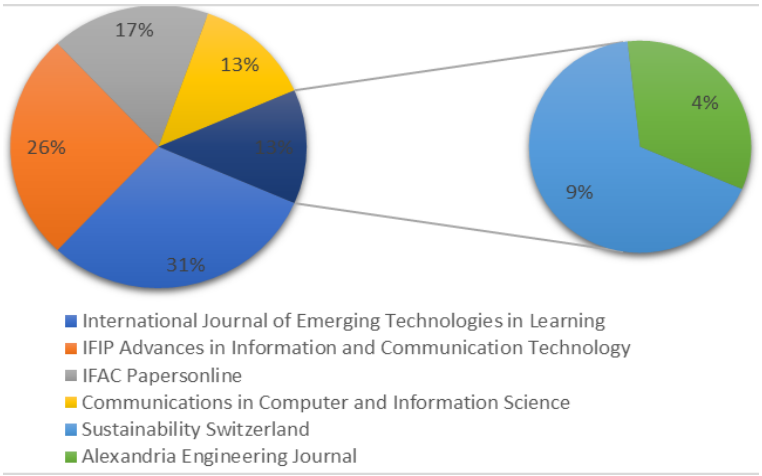

Figure 4: The most cited journals related to the digitalization of the education system.

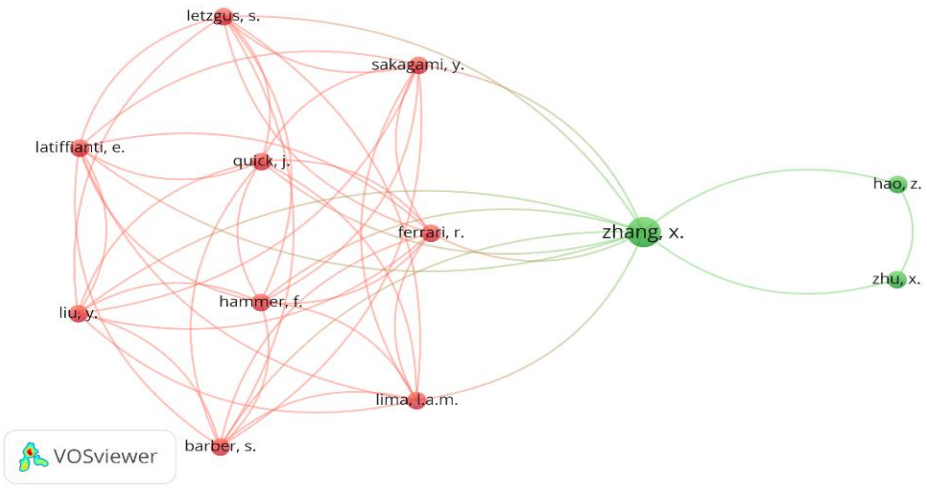

Figure 5: Network map of top co-authorships.

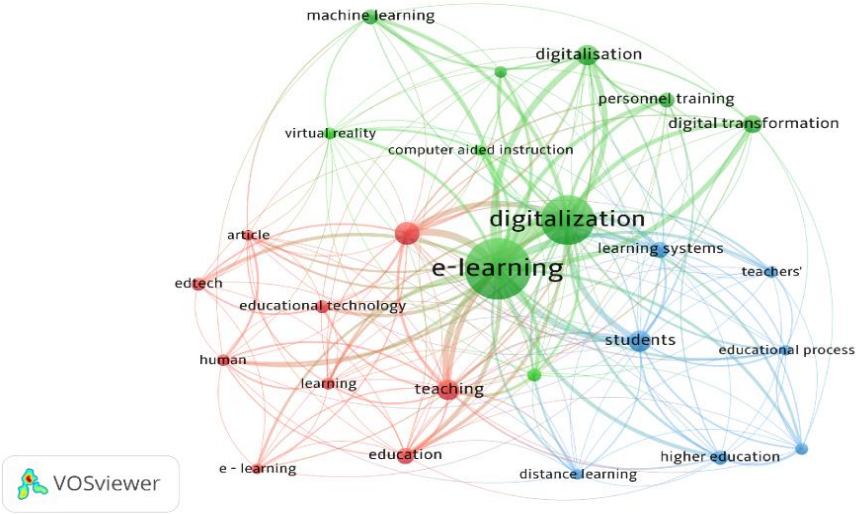

Figure 6: Network map of top keywords based on the total link strength.

3.6 Top Co-Authorships and Keyword Network

Using VOSviewer, it is possible to produce co-authorship networks, keyword co-occurrence maps, citation networks, bibliographic coupling, and co-citation visualizations based on bibliographic datasets. The software supports file formats such as .txt, .ris, and .csv exported from databases like Scopus and a map of co-authorship and keyword co-occurrences (shown in Fig. 5, 6) were created using the software. The co-authorship analysis resulted in a network of 1475 authors. Only authors having a minimum of two publications on the topic of education were included. There are 12 items distributed over 2 clusters: cluster 1 (9 items), cluster 2 (3 items).

Figure 5 illustrates the co-authorship network generated using VOSviewer, highlighting the collaborative relationships among researchers. The keyword analysis identified 1017 unique terms. After filtering out low-frequency items (those occurring fewer than 56 times), 25 dominant keywords were identified. Using VOSviewer, a co-occurrence network was constructed, revealing four main clusters: cluster 1(article, e-learning, edtech, education, engineering education, human, learning, teaching) cluster 2 (digital technologies, digital transformation, digitalization, e-learning, machine learning, personal training) cluster 3 (distance

learning, educational procces, high education, learning systems, students, teachers) cluster 4 (computer aided instructior, teaching and learning, virtual reality). These clusters collectively illustrate the intellectual structure of research on digital transformation in education across the different region, emphasizing the central role of technology-driven teaching, learning, and innovation.

As illustrated in Figure 6, keyword co-occurrence analysis reveals the dominant thematic clusters related to e-learning, digital pedagogy, and educational technologies.

4 DISCUSSION

The results confirm the growing strategic importance of digital transformation in vocational education, particularly after the COVID-19 pandemic accelerated the adoption of hybrid and online learning systems. Unlike earlier studies focused primarily on technological implementation, the present analysis highlights the increasing importance of pedagogical adaptation, teacher digital competencies, and institutional readiness.

- SMEs-small and medium enterprises;
- ICT-information and communication technology;
- CPS-cyber-physical systems;
- Smart PLS- partial least squares;
- GTSC- Geometrical tolerance specification callouts;
- CUPMF- Convolutional Pooled-Probability Matrix Factorization;
- CPD- continuing professional development;
- STEM - Science, Technology, Engineering and Mathematics;
- EMR-electronic medical record;
- TOPSIS- Technique for Order of Preference by Similarity to Ideal Solution.

The results of the bibliometric analysis show that research on the digitization of Professional Education has expanded significantly in recent years, and they are formed in five main areas (Table 3). The first line - the introduction of e-learning adoption 27% - focuses on the transition from traditional teaching to digital learning environments. Research in this area highlights the level of training of educational institutions, digital literacy of teachers and the importance of integrating electronic management systems into the educational process. Based on the studies reviewed, the state of Russia ranks 1st (20%) in this direction. However, most of the work was carried out within the framework of higher education institutions, and the application of these results to the professional education system has not yet developed sufficiently.

The second direction-digital pedagogy 25.8% - shows a growing number of approaches aimed at interactive teaching models that center the student. Researchers emphasize the importance of methodological flexibility and constant professional development of teachers for effective digital pedagogy. At the same time, applied research is less than theoretical developments, which indicates the need for experimentally verified results in real educational processes. In this direction, the state of Germany is gaining 30%. The results of the analyzed articles prove that there is a growing interest in creating mixed (blended) and hybrid teaching models.

The third and fourth directions - innovations in educational technology 13%, as well as improvements in evaluation models 3.2% - show an inextricable link between technological renewal and pedagogical efficiency. Innovative tools such as artificial intelligence, virtual laboratories and immersive simulations are effectively used in the formation of professional skills. At the same time, evaluation systems are also enriched with new approaches based on the measurement of digital competencies. This circumstance leads to the fact that technology is considered not only as an auxiliary tool, but also as an integral part of the teaching process. On these routes, the state of China occupies 17%. The latter direction- (other studies 31%) - includes cross-sectoral developments that link digitization with issues such as sustainability and adaptation to the labor market.

In general, this discussion confirms that the process of digital transformation in professional education is developing, but in the cross section of Regions and areas, this process is not at the same level. Future research should focus on creating unified digital pedagogy models in the context of professional education and assessing the long-term effectiveness of digital solutions. Also, increased cooperation between scientific institutions and the industrial sector is instrumental in adapting digital competencies to the needs of the labor market.

Table 3: Thematic clustering of publications based on five main research areas.

Direction	Method	Country	Keywords	Number of articles
E-learning adoption	Survey, Literature review, case study, Empirical analysis, quantitative research	Germany, India, Russia, Romania, China, Uganda,South Korea, Uzbekistan, Bulgaria, Ireland, Croatia, Poland, Sweden, Syria, Finland, South Africa	Online teaching, education, qualitative study, EMR, educational technologies, academic progress, school computers, scalability, ICT system administration, secondary school education, sustainability, course, process, CPD, Teaching staff, creative methods, technologies, SMEs.	25
Digital pegagogy	Q-methodology, Test, survey, literature review, empirical research, reviewof a monograph, analysis, case study, Mixed methods	Germany, Finland, India, Greece, Spain, Russia, China, Sweden, Romania, Mexico, Bulgaria, Finland	teacher role, virtual classroom, academic anxiety, computational thinking, higher education, digital pedagogy, CUPMF, learning analytics, distance learning, metaverse, STEM education, self- education, innovation, teacher activity.	24
Edtech innovation	Case study, analysis, approach, systematic literature review, empirical research, quantitative research	Germany, Kosovo, Latvia Russia, India, South Africa, Netherlands, China, Australia Finland	Social media Artificial, intelligence, teaching, basic education, teacher support systems, smart PLS, knowledge transfer, TOPSIS Onco-fertility, Logistics education, Virtual reality, Video reporting.	12
Evaluation models	Survey, case study, model created	Germany, Ireland, Korea,	E-assessment, online delivery, evaluation criteria.	3
Others	Review article, Case study, test, Data-driven optimization, survey, semi-structured interviews, analysis, empirical research, practical experience, deep learning, model created.	Egypt, Sweden, Norway, Netherlands, Bulgaria, UK, Austria, Germany, Italy, China, Russia.	Machine learning, trends, Sustainable, mobility, collaboration, cybersecurity, digital lean manufacturing, GTSC, digitalization, CPS, virtualization, self-learning, smart manufacturing, industrial digitalization, training program methods.	29

5 LIMITATIONS

The limitation of this study is that the analysis was based only on Scopus-indexed publications from 2017 to 2024. This method was selected to avoid potential formatting challenges that might arise when using data from multiple sources. However, this strategy restricts the study to English-language papers available in Scopus, thereby excluding relevant literature from other databases and in different languages. Future research could address this limitation by incorporating data from a range of databases and considering literature published in multiple languages.

6 CONCLUSIONS

A bibliometric analysis of 93 Scopus-indexed publications covering the period from 2017 to 2024 identified key research trends, emerging topics and leading regions in the field of digitalization in vocational education. The analysis showed that the most productive years were 2021, 2022 and 2023, reflecting the rapid digital transformation that has taken place in higher and vocational education during and after the pandemic. The journals with the highest publication activity were the International Journal of Emerging Technologies in Education, IFIP Advances in Information and Communication Technologies and IFAC Papers online. The most active countries were Germany, Russia, Finland and China, representing regions with strong institutional capacity and high participation in digital education reforms. The study highlighted that the majority of publications focused on e-learning systems, digital pedagogy, educational technologies and digital competence of teachers. The 65% increase in the number of publications indicates that digitalization has become a strategic priority for

improving the quality, accessibility and efficiency of vocational education. The analysis showed that digital tools and artificial intelligence technologies are increasingly being used to improve teaching processes, research practices and management systems in technical universities. However, the study identified a lack of long-term and comparative studies on the practical application of digital transformation in professional settings. Strengthening cooperation between researchers, educators and policymakers remains crucial for achieving sustainable progress. The bibliometric approach has proven valuable for mapping international collaboration, identifying thematic gaps and serving as a historical and predictive reference for future research. Further development of this field requires combining quantitative and qualitative approaches to create comprehensive digital strategies for modern vocational education systems worldwide. The findings may support policymakers, university administrators, and researchers in developing evidence-based strategies for sustainable digital transformation in vocational education systems.

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