A Comprehensive Bibliometric Analysis of University 4.0: Knowledge Structure, Research Trends, and Evolution (2009–2025)

تحليل ببليومتري شامل للجامعة 4.0: البنية المعرفية واتجاهات البحث وتطوره (2009 2025)

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Abstract

This study aims to present a comprehensive bibliometric analysis of global research on University 4.0 from 2009 to 2025 using Scopus data. A total of 126 publications were examined through descriptive indicators, co-authorship networks, keyword co-occurrence mapping, thematic analysis, and visualizations of intellectual linkages. The findings show a marked increase in scholarly output after 2018, driven by growing interest in digital transformation, smart universities, and Education 4.0. Leading sources include *Education in the Asia Pacific Region* and *Sustainability*, while highly cited studies focus on sustainability, engineering education, and technological innovation. At the geographical level, the Russian Federation, Morocco and Kyrgyzstan appear as leading contributors. Overall, this study offers a systematic and up-to-date overview of the thematic development and intellectual foundations of University 4.0, offering a useful reference for future research and policy formulation.

Keywords: University 4.0; Higher Education 4.0; Industry 4.0; Bibliometric Analysis.

JEL Classification Codes: I23, I21, O33, O30, C89

ملخص:

تهدف هذه الدراسة إلى تقديم تحليل ببليومتري شامل للأبحاث العالمية حول الجامعة 4.0 خلال الفترة من 2009 إلى 2025 اعتمادا على بيانات Scopus . تم فحص ما مجموعه 126 منشورا باستخدام المؤشرات الوصفية، وشبكات التأليف المشترك، ورسم خرائط التشارك في الكلمات المفتاحية، والتحليل الموضوعي، وتصوير الروابط الفكرية. تُظهر النتائج ارتفاعا واضحا في الإنتاج العلمي بعد عام 2018، مدفوعا بتزايد الاهتمام بالتحول الرقمي، والجامعات الذكية، والتعليم 4.0. كما تشمل أبرز مصادر النشر في *Education in the Asia Pacific Region* و *Sustainability*، بينما تركز الدراسات الأكثر استشهادا على الاستدامة، وتعليم الهندسة، والابتكار التكنولوجي. وعلى المستوى الجغرافي، تبرز كل من روسيا، والمغرب، وقيرغيزستان كأكثر الدول إسهاما في هذا المجال. وفي المجمل، تقدم هذه الدراسة خريطة محدثة ومنهجية للتطورات الموضوعية والأسس الفكرية للجامعة 4.0، مما يوفر مرجعا مفيدا للأبحاث المستقبلية وصياغة السياسات.

الكلمات المفتاحية: الجامعة 4.0؛ التعليم العالي 4.0؛ الصناعة 4.0؛ التحليل الببليومتري.

تصنيف JEL : I23، I21، O33، O30، C89

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1. Introduction

The emergence of the Fourth Industrial Revolution has brought significant changes across many sectors, including higher education. As universities begin to incorporate digital technologies, automation, artificial intelligence, and smart systems into their core activities, the concept of University 4.0 has gained growing academic interest. This model represents a novel institutional paradigm that fosters innovation-oriented learning, human–machine interaction, data-driven decision-making, and digitally enhanced teaching and management environments. It is closely linked to the principles of Industry 4.0 and aligns with broader shifts toward digital economies and sustainable development.

Over the past decade, higher education systems worldwide have undergone rapid digital transformation, a process that accelerated further in response to the COVID-19 pandemic. This shift has catalyzed research on smart campuses, e-learning ecosystems, modernized engineering education, and digital learning technologies. In many developing and emerging economies, interest in Fourth Generation Universities has grown considerably as countries seek to modernize their higher education sectors. Algeria is a notable example, where national strategies increasingly emphasize digital transformation, innovation, entrepreneurship, and the adoption of smart educational technologies. Algerian universities are gradually adopting University 4.0 principles to improve educational quality, institutional performance, and competitiveness within a fast-changing global knowledge environment.

Despite this rising interest, the literature on University 4.0 remains fragmented, with studies published across a wide range of disciplines, countries, and academic outlets. This fragmentation has limited our understanding of the field's knowledge structure, its thematic evolution, collaboration networks, and intellectual underpinnings. Although related concepts such as Education 4.0 and digital transformation in higher education have been investigated, a comprehensive bibliometric analysis focused specifically on University 4.0 is still notably absent. A systematic, data-driven analysis is therefore needed to clarify how the field has developed, which themes define its intellectual landscape, who the leading contributors are, and how research priorities have changed over time.

To address these gaps, this study conducts a large-scale bibliometric analysis of University 4.0 research published between 2009 and 2025, using data extracted exclusively from the Scopus database. By combining descriptive indicators, keyword-based conceptual mapping, co-authorship analysis, thematic evaluation, and visualizations of intellectual linkages, the study provides a comprehensive overview of the field and identifies its key theoretical and practical directions.

Accordingly, this study aims to:

- Examine the evolution and growth of scientific production related to University 4.0 (2009–2025).
- Identify the most influential journals and highly cited articles in the field.
- Analyze the geographical and institutional distribution of research output.
- Explore dominant themes, conceptual clusters, and emerging topics using keyword analysis.
- Investigate co-authorship networks and collaboration patterns.
- Evaluate the maturity and centrality of thematic areas through a thematic map.

- Map intellectual linkages among authors, sources, and keywords through a three-field plot.

These objectives lead to the following research questions:

- How has scientific production on University 4.0 evolved over time?
- Which journals and articles play the most influential roles in shaping the field?
- Which countries and institutions contribute most actively to University 4.0 research?
- What are the dominant themes and conceptual structures in the literature?
- How do authors collaborate within this research domain?
- What insights does the thematic map provide regarding the development and relevance of key topics?
- How are authors, sources, and keywords interconnected within the intellectual structure of the field?

Overall, this study presents the most extensive bibliometric analysis of University 4.0 to date. Its findings offer valuable insights for policymakers, educators, and researchers seeking to understand emerging trends and future directions in the digital transformation of higher education—both globally and within developing contexts such as Algeria.

2. Theoretical Background

2.1. Evolution of the University Concept: From 1.0 to 4.0

The concept of the university has progressed through four major stages that reflect broader shifts in society and technology. University 1.0 represented the traditional model, centered mainly on teaching and the one-way transmission of knowledge from instructor to student. As higher education expanded, University 2.0 emerged, emphasizing mass education, standardized programs, and the introduction of quality assurance systems.

With the rise of the knowledge economy, University 3.0 brought research, innovation, and entrepreneurship to the forefront, strengthening ties between universities, industry, and society. The current stage, University 4.0, is shaped by the digital transformation era and incorporates advanced technologies including artificial intelligence, big data, and the Internet of Things to create more flexible, personalized, and technology-enhanced learning environments.

This progression reflects a clear shift from a traditional, content-based model of education toward a more dynamic, innovation-driven, and digitally supported approach (Vu et al., 2024).

2.2. Defining University 4.0

University 4.0 refers to a contemporary model of higher education shaped by the technologies of the Fourth Industrial Revolution. It brings together artificial intelligence, big data, the Internet of Things, and cyber-physical systems to support teaching, research, and institutional management (Miranda et al., 2021).

Chernaya et al. (2023) describe University 4.0 as an integrated framework that aligns educational policy, scientific research, and innovation through deep digital transformation.

In a similar vein, Giesenbauer & Müller-Christ (2020) emphasize that this model aims to reshape higher education by fostering smart learning environments and improving educational processes through advanced digital tools and Industry 4.0 technologies.

According to Nilüfer¨ulker and Otrar (2025), University 4.0 is grounded in digital competencies, innovation, and strong university–industry collaboration, positioning it as a key

driver in the development of technology-oriented knowledge economies. Dou (2025) further highlights its role in enabling flexible, interactive, and personalized learning systems that equip students with the digital skills required for future labor markets.

Taken together, these perspectives position University 4.0 as an innovative, digitally enabled, and collaborative higher education model designed to enhance educational quality, foster innovation, and strengthen digital competencies in response to the rapid changes brought about by the Fourth Industrial Revolution.

2.3. Conceptual Foundations of University 4.0

The concept of University 4.0 is rooted in several interconnected theoretical foundations. At its core, it emerges as a response to the Fourth Industrial Revolution, which is marked by the rise of cyber-physical systems, big data, artificial intelligence, cloud computing, and the Internet of Things. These technologies are reshaping expectations for higher education institutions, requiring them to integrate digital infrastructures into teaching, research, and governance. As noted by Giesenbauer and Müller-Christ, (2020), the changes brought by Industry 4.0 call for a "multidimensional and networked organizational model" to ensure that universities remain relevant while contributing to sustainable development.

A second foundation stems from the principles of Education 4.0, which provide the pedagogical basis for University 4.0. This approach emphasizes adaptive, personalized, and data-informed learning environments supported by smart classrooms, learning analytics, and hybrid teaching models. According to Chernaya et al. (2023), University 4.0 reflects a shift toward competency-based education that integrates digital economy skills, entrepreneurial competencies, and advanced technologies into academic programs. In this framework, learning moves beyond the transmission of knowledge toward the development of capabilities and innovation.

A third pillar is grounded in innovation ecosystem theory and models of open collaboration. From this perspective, the university acts as a key node within a broader network involving industry, government, and civil society—consistent with the triple helix and quadruple helix frameworks. Giesenbauer and Müller-Christ, (2020) emphasize that such collaborative, transdisciplinary networks are essential for addressing global challenges related to digitalization, sustainability, and societal transformation.

Sustainable development frameworks have also become increasingly central to the conceptualization of University 4.0. In this regard, universities are expected not only to drive economic innovation but also to contribute to social responsibility and human-centered progress. Rosak Szyrocka et al. (2022) highlight the role of University 4.0 in supporting transitions toward Society 5.0 by integrating sustainability principles and promoting human-centric technological ecosystems.

Collectively, these foundational elements constitute the theoretical architecture: Industry 4.0 technologies, Education 4.0 pedagogical reforms, innovation ecosystem theory, and sustainability-oriented approaches form the theoretical architecture of University 4.0. They position it as a digitally enabled, learner-centered, innovation-driven, and socially embedded model of higher education.

2.4. Theoretical Frameworks: Helix Models in Higher Education

The innovation ecosystem perspective in higher education is strongly reflected in the Triple Helix and Quadruple Helix models. The Triple Helix framework highlights the

interaction between universities, industry, and government as key drivers of knowledge creation and innovation (Carayannis & Campbell, 2010; Etzkowitz & Leydesdorff, 2000).

Building on this idea, Carayannis and Campbell (2010) extend the model to a Quadruple Helix by adding a fourth dimension—the media- and culture-based public—thereby broadening the framework to include civil society and public participation.

Together, these models position University 4.0 within a wider innovation system, where the university operates not only as a center for teaching and research but also as an active node within a multi-actor network. This perspective underscores the role of universities in advancing knowledge-driven, digitally supported socio-economic transformation.

2.5. University 4.0 and Its Alignment with Society 5.0

The strategic alignment between University 4.0 and Society 5.0 reveals the evolving role of higher education in advancing socio-technological change. University 4.0 focuses on digitalization, smart learning environments, AI-supported pedagogies, and innovation ecosystems, positioning universities as key actors in the knowledge economy. Society 5.0, as described by Deguchi et al. (2020), envisions a "super-smart," human-centered society in which technological progress is directed toward addressing societal needs and improving overall well-being.

Within this framework, University 4.0 serves as an important enabler of Society 5.0 by developing advanced digital skills, encouraging interdisciplinary and problem-oriented research, and supporting innovations that link economic development with social inclusion. Rosak Szyrocka et al. (2022) further note that the digital transformation of universities contributes to sustainable development goals and supports the transition toward human-centered technological ecosystems. In this sense, the relationship between University 4.0 and Society 5.0 represents a complementary synergy: University 4.0 provides the institutional capabilities and technological foundations, while Society 5.0 offers the guiding vision for a socially responsive digital future.

2.6. Research Gap and Rationale for the Study

Although the concept of University 4.0 has gained increasing scholarly attention in recent years, the existing research remains dispersed across technological, pedagogical, and institutional domains. Much of the prior literature addresses isolated dimensions such as smart education initiatives, digital transformation processes, or innovation ecosystem frameworks yet few studies provide an integrated or longitudinal view of how the field has developed over time. This fragmentation highlights the necessity for a systematic bibliometric review that can delineate the dominant research trajectories, identifying influential authors and sources, mapping the underlying intellectual structure, and detecting emerging thematic clusters within the University 4.0 landscape.

3. Methodology and data

3.1. Bibliometric Method and Indicators

This study applies a bibliometric approach to analyze the development and thematic structure of research on University 4.0. The method combines quantitative and qualitative techniques, including citation analysis, co-authorship and co-occurrence networks, and scientific mapping. Visualization tools such as the Word Cloud, Tree map, and thematic mapping were also used to clarify the conceptual landscape of the field.

Descriptive indicators were employed to assess annual publication trends, citation patterns, and the distribution of research across countries, institutions, and sources. Relational indicators supported the examination of collaboration structures and thematic linkages. Co-authorship analysis highlighted patterns of cooperation among authors and institutions, while keyword co-occurrence analysis helped identify core themes and conceptual clusters. Additional tools, such as the thematic map and the three-field plot, provided further insight into the evolution and intellectual organization of the field.

Together, the bibliometric method and its analytical indicators provide a holistic yet succinct perspective of the scholarly activity surrounding University 4.0 and help clarify its conceptual foundations and research dynamics.

3.2. Data Sources

The Scopus database was selected as the primary source for document search and extraction due to its extensive coverage of scientific literature and the high quality of its bibliometric data. As one of the largest curated citation databases, it offers broad access to both global and regional scientific journals. Its comprehensive indexing of journals, conference proceedings, and review articles—combined with high quality bibliographic metadata such as authorship, affiliations, keywords, citations, and references—makes it particularly suitable for mapping research trends and knowledge structures. Using Scopus ensures reliability, consistency, and replicability throughout the analytical process.

3.3. Search Strategy and Data Preparation

This research was carried out in November 2025. A systematic literature search was applied using carefully selected keywords representing the University 4.0 paradigm. The search query, was executed across the Title, Abstract, and Keyword fields, included the terms:

"University 4.0" OR "Higher Education 4.0" OR "Fourth Generation University" OR "4th Generation University"

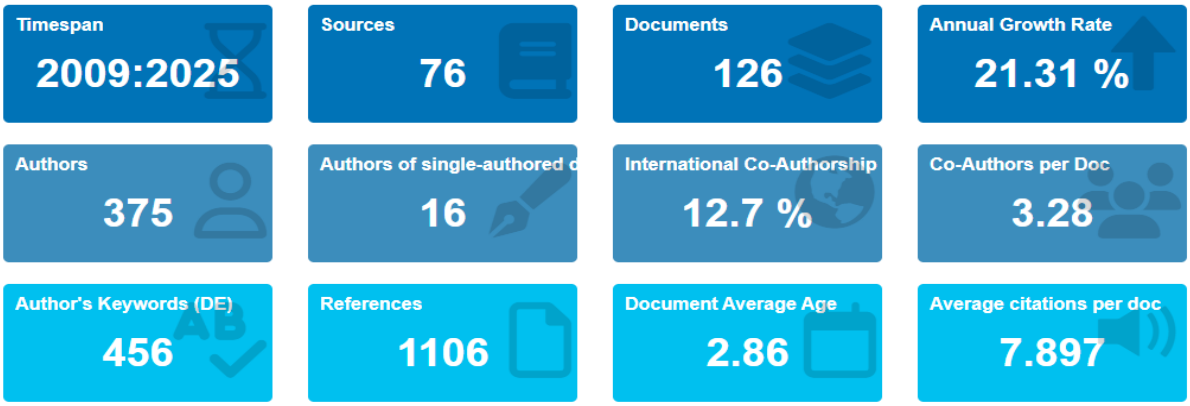
The study focuses on publications from 2009 to early 2025, beginning when the concept of University 4.0 first emerged alongside Industry 4.0 and higher education digitalization. Extending the analysis to 2025 captures recent developments driven by AI, digital transformation, and post-pandemic changes, enabling a comprehensive view of the evolution of University 4.0 research.

The initial search found 151 documents. Following the exclusion of non-English publications, books, editorials, letters, errata, and retracted items, the search left 126 documents for analysis, and these records served as the analytical dataset for this work.

Data cleaning included removing duplicates and standardizing metadata such as author names, affiliations, and keywords. The dataset comprised peer reviewed journal articles, review papers, conference contributions, and book chapters, ensuring balanced conceptual and empirical coverage of University 4.0 research.

A summary of the dataset is shown in Fig. 1.

Fig (1): Overview of research on University 4.0 Research (2009–2025)



Source: Generated by the authors using Bibliometrix R package.

3.4. Software Tools

Two analytical tools were used to conduct the bibliometric analysis.

- **VOSviewer (version 1.6.20)** was employed to map the social and conceptual structures of the dataset. The software was used to generate co-authorship and keyword co-occurrence networks, providing clear visualizations of collaboration patterns and thematic linkages within the field.
- **Bibliometrix (version 2025.09.2+418)** accessed through the Biblioshiny interface in R (Aria & Cuccurullo, 2017), supported the descriptive and thematic analyses. It facilitated the examination of annual publication trends, source and citation distributions, institutional and geographical contributions, as well as keyword-based visualizations and thematic structure assessments. Bibliometrix also enabled the exploration of conceptual and intellectual linkages through advanced mapping techniques.

The combined use of both tools ensured a rigorous and comprehensive analytical framework, integrating robust descriptive indicators with high resolution bibliometric visualizations appropriate for scholarly research in a rapidly evolving field.

4. Results

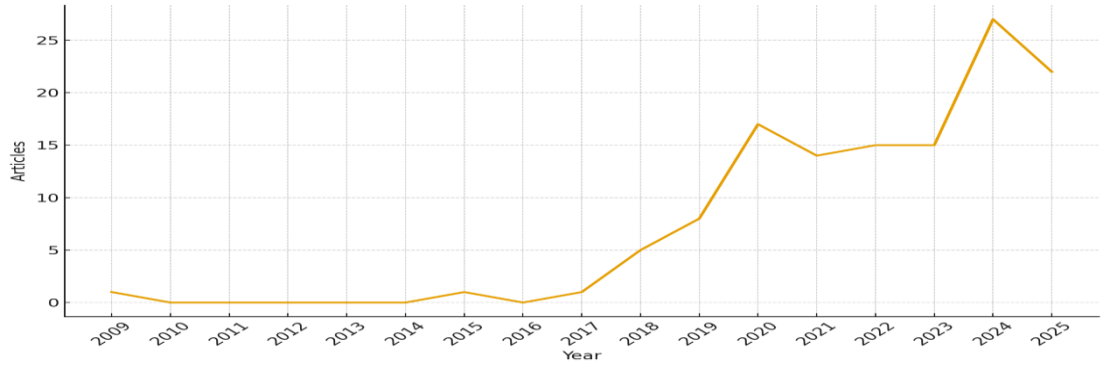
4.1. Descriptive Analysis

4.1.1. Annual Scientific Production

Fig. 2 presents the annual scientific production related to University 4.0 between 2009 and 2025. Research activity during the first several years (2009–2017) remained limited, which aligns with the fact that the concept was still in its early formative stage. A noticeable uptick emerged in 2018, followed by a more pronounced surge from 2019 to 2021, reflecting the growing influence of digital transformation across higher education systems. Publication activity reaches its highest levels in 2023 and 2024, a period marked by global developments in smart campuses, the integration of Industry 4.0 technologies, and the post-pandemic acceleration of digital solutions. The apparent decline in 2025 is likely an artifact of the dataset's incomplete coverage for that year.

Overall, the pattern indicates a clear shift from a nascent idea to a rapidly expanding area of research.

Fig (2): Annual Scientific Production in University 4.0 Research (2009–2025)



Source: Developed by authors from Scopus dataset (retrieved November 2025).

4.1.2. Most Productive Sources and Highly Cited Documents

The publication sources listed in Table (1) show that research on University 4.0 comes from a wide range of disciplines. *Education in the Asia Pacific Region* is the most active source with seven publications. It is followed by *Sustainability (Switzerland)* and *Lecture Notes in Networks and Systems*, each with five articles, reflecting strong contributions in sustainability and engineering related topics. Several other sources, such as *Frontiers in Education*, *E3S Web of Conferences*, and *Advances in Science, Technology and Innovation* (each with four publications), highlight continued interest in educational innovation and technology integration. Conference proceedings—including *IT & QM and IS 2022* and *Innovation in the University 4.0 System Based on Smart Technologies* (three publications each), as well as *Proceedings on Engineering Sciences* (two publications)—add focused research on management, cybersecurity, and smart systems. *Procedia Computer Science* (two publications) further contributes to work related to digital infrastructure and computational approaches.

Overall, these sources show that University 4.0 research is truly multidisciplinary, bringing together contributions from education, sustainability, engineering, and technological innovation.

Table (1): Top Publication Sources in University 4.0 Research

Rank	Journal	Count
1	*Education in the Asia Pacific Region*	7
2	*Sustainability (Switzerland)*	5
3	*Lecture Notes in Networks and Systems*	5
4	*Frontiers in Education*	4
5	*E3S Web of Conferences*	4
6	*Advances in Science, Technology and Innovation*	4
7	*Proceedings of the 2022 International Conference on Quality Management, Transport and Information Security (IT & QM and IS 2022)*	3
8	*Innovation in the University 4.0 System Based on Smart Technologies*	3
9	*Proceedings on Engineering Sciences*	2
10	*Procedia Computer Science*	2

Source: Developed by authors from Scopus dataset (retrieved November 2025).

Most Cited Articles (Table 2) illustrates the field's multidimensional nature. Giesenbauer and Müller-Christ (2020) and Rosak Szyrocka et al. (2022), both published in *Sustainability*, highlight the strong link between University 4.0 and sustainability oriented transformation.

Giang et al. (2021), Goh and Abdul Wahab (2020), and Safiullin and Akhmetshin (2019) focus on engineering education, digital learning, and the skills required in Industry 4.0. Corazza and Saluto (2021) in *IEEE Transactions on Engineering Management* and Magni et al. (2020) in *International Journal of Management and Financial Accounting* add managerial and organizational perspectives related to digital and financial innovation in universities. Chigbu et al. (2023) extend the discussion to include social and human centered aspects in *Social Sciences & Humanities Open*, while Kerroum et al. (2020) focus on digital infrastructures and smart learning environments in *Procedia Computer Science*. Finally, Pawowski (2009) provides an early conceptual contribution on the evolution of university models, serving as a foundational reference for later work on University 4.0.

Together, these studies constitute the intellectual core of the field.

Table (2): Top 10 Most Cited Articles in University 4.0 Research

Rank	Paper	DOI	Total Citations
1	GIESENBAUER, 2020, *Sustainability*	10.3390/SU12083371	130
2	GIANG, 2021, *International Journal of Engineering Pedagogy*	10.3991/IJEP.V11I2.17515	59
3	CORAZZA, 2021, *IEEE Transactions on Engineering Management*	10.1109/TEM.2020.3020736	53
4	CHIGBU, 2023, *Social Sciences & Humanities Open*	10.1016/j.ssaho.2023.100419	41
5	ROSAK SZYROCKA, 2022, *Sustainability*	10.3390/su142316043	39
6	GOH, 2020, *International Journal of Learning, Teaching and Educational Research*	10.26803/ijlter.19.1.9	36
7	SAFIULLIN, 2019, *International Journal of Engineering and Advanced Technology*	10.35940/ijeat.A3097.109119	36
8	PAWOWSKI, 2009, *Higher Education in Europe*	10.1080/03797720902747017	32
9	KERROUM, 2020, *Procedia Computer Science*	10.1016/j.procs.2020.07.057	30
10	MAGNI, 2020, *Int J Manag Financ Account*	10.1504/IJMFA.2020.109129	24

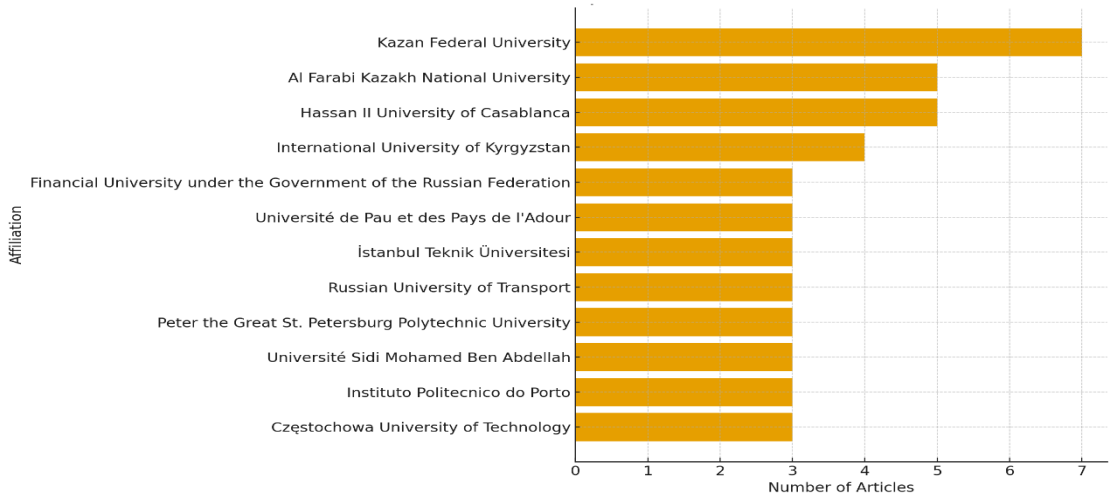
Source: Generated by the authors using Bibliometrix R package.

4.1.3. Geographical and Institutional Distribution

Institutional productivity, as shown in Fig. 3, exhibits notable variation across the universities contributing to University 4.0 research. Kazan Federal University records the highest output, followed by Hassan II University of Casablanca and Al Farabi Kazakh National University. Several other institutions contribute smaller yet meaningful publication counts, resulting in a research landscape that is both diverse and geographically dispersed.

Overall, the pattern reflects increasing international engagement with University 4.0 themes, particularly across Eurasia, North Africa, and Central Asia.

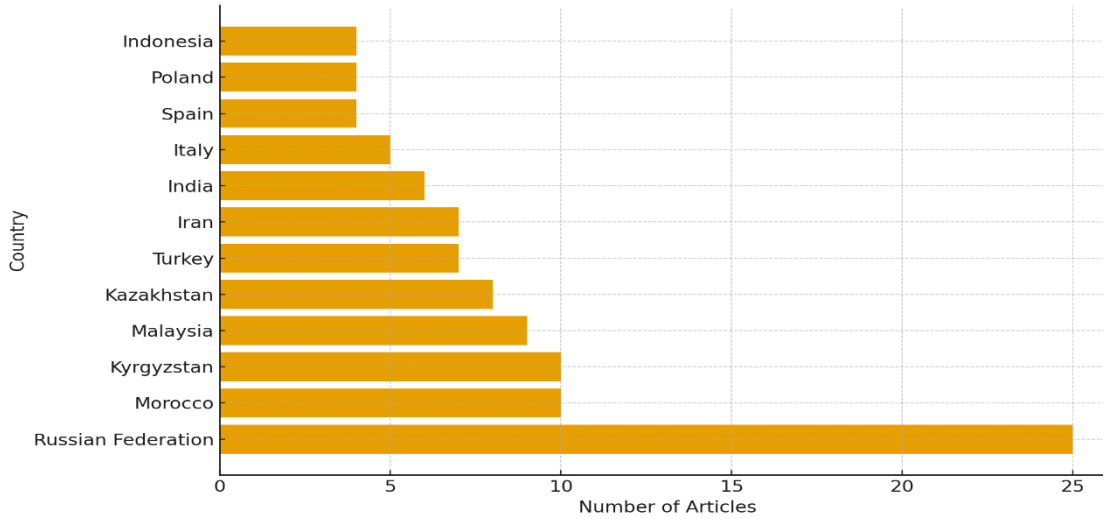
Fig (3): Top Productive Affiliations in University 4.0 Research



Source: Developed by authors from Scopus dataset (retrieved November 2025).

Country level productivity, as shown in Fig. 4 highlights a clear concentration of research activity. The Russian Federation leads with 25 publications, while Morocco and Kyrgyzstan follow with 10 each. Several countries in Southeast Asia and the Middle East—such as Malaysia, Kazakhstan, Turkey, and Iran—also demonstrate strong participation.
This indicates that efforts toward educational modernization and digital transformation are gaining traction across these regions.

Fig (4): Top Contributing Countries in University 4.0 Research



Source: Developed by authors from Scopus dataset (retrieved November 2025).

4.1.4. Keyword Based Descriptive Visualizations

The Word Cloud Fig. 5 highlights the most frequent keywords, with "university 4.0," "digital transformation," "higher education," "industry 4.0," and "e learning" appearing most prominently. These terms represent the conceptual core of the field, emphasizing the intersection between technological innovation and education.

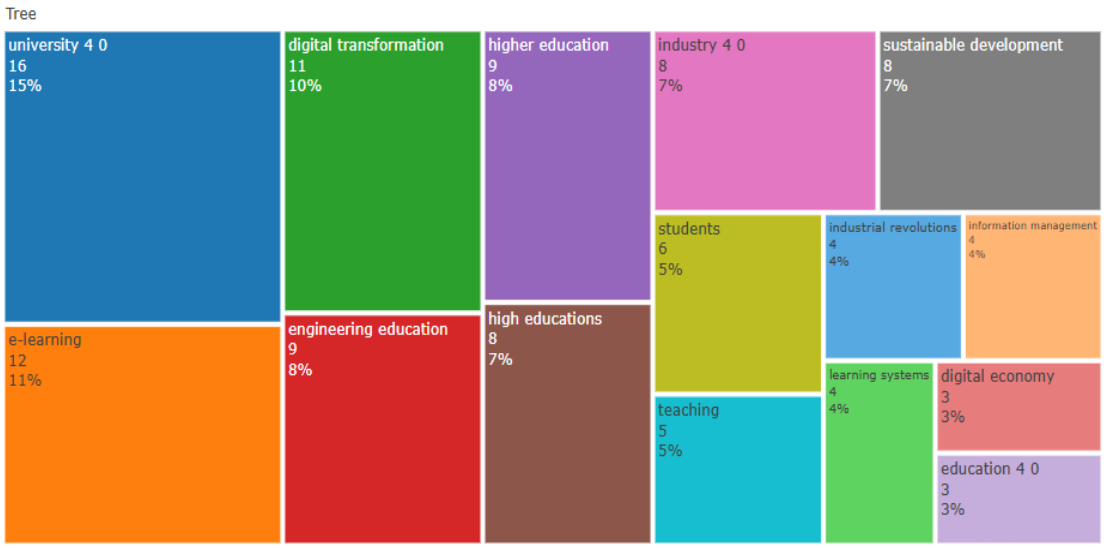
Fig (5): Word Cloud of the Most Frequent Keywords in University 4.0 Research



Source: Generated by the authors using Bibliometrix R package.

The Tree map in Fig. 6 presents the distribution of the most frequent keywords in the University 4.0 literature. Larger segments correspond to terms such as “university 4.0,” “digital transformation,” “higher education,” “industry 4.0,” and “e learning,” indicating their central role in the field. This visualization helps clarify how key themes are structured and shows the close connection between technological innovation and developments in higher education.

Fig (6): Tree Map Showing the Distribution of the Most Frequent Keywords



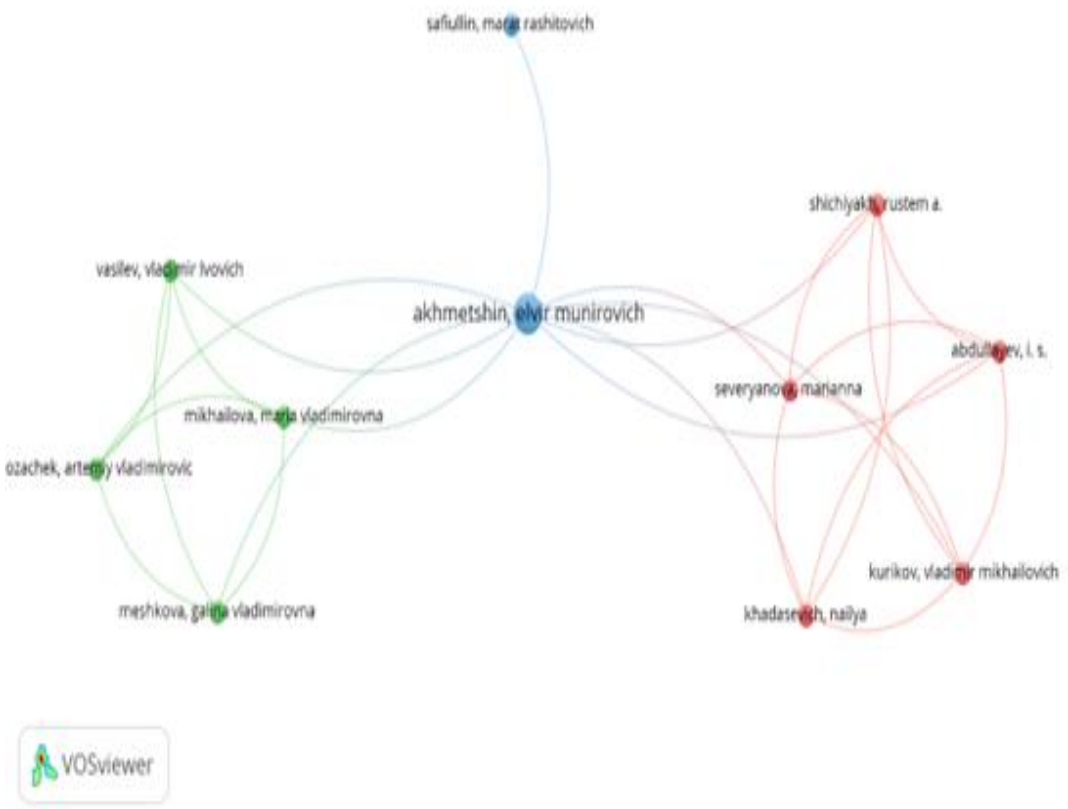
Source: Generated by the authors using Bibliometrix R package.

4.2. Social Structure Analysis

4.2.1. Co-authorship Network

The co-authorship network shown in Fig. 7 highlights several clusters of collaboration within the University 4.0 research community. Akhmetshin Elvir Munirovich appears as a central link connecting multiple authors and groups, indicating an active role in shaping collaborative work in the field. The network shows a moderate level of fragmentation, suggesting that research collaborations are still developing and have not yet formed a fully integrated international structure.

Fig (7): Co-authorship Network Among Authors in University 4.0 Research



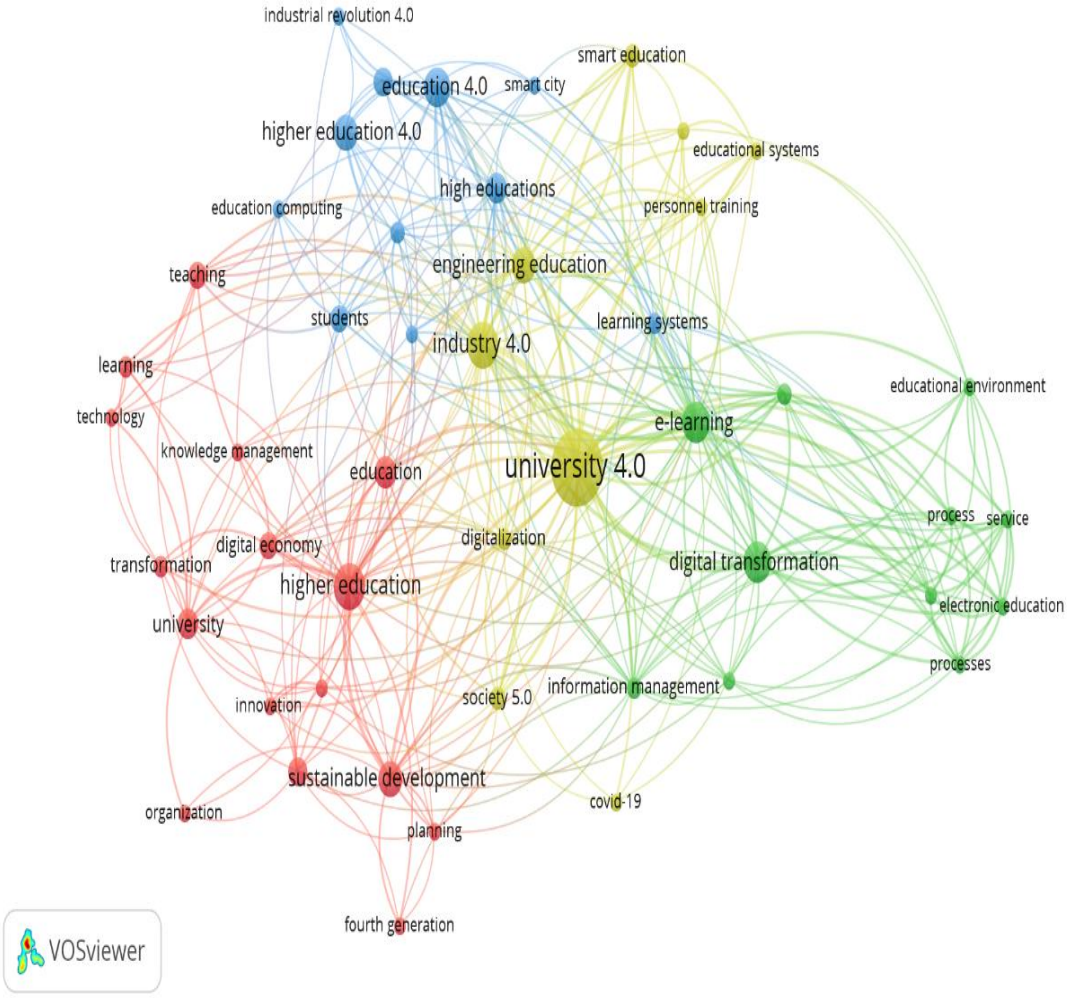
Source: Generated by the authors using VOSviewer .

4.3. Conceptual Structure Analysis

4.3.1. Keyword Co-occurrence Network

The keyword co-occurrence network in Fig. 8 shows four main thematic clusters within the University 4.0 literature. The dominant themes center on digital transformation, e learning environments, engineering education, innovation, and sustainability. The strong connections between these clusters underscore the multidisciplinary nature of the field and how its core topics intersect across different research areas.

Fig (8): Keyword Co occurrence Network in University 4.0 Research



Source: Generated by the authors using VOSviewer .

4.3.2. Thematic Cluster Map

The thematic map in Fig. 9 provides a clearer understanding of how research areas within the University 4.0 literature are positioned in terms of their maturity and importance.

Motor themes, such as e learning and digital transformation, occupy a central and well-developed space in the field, indicating their strong influence and ongoing relevance.

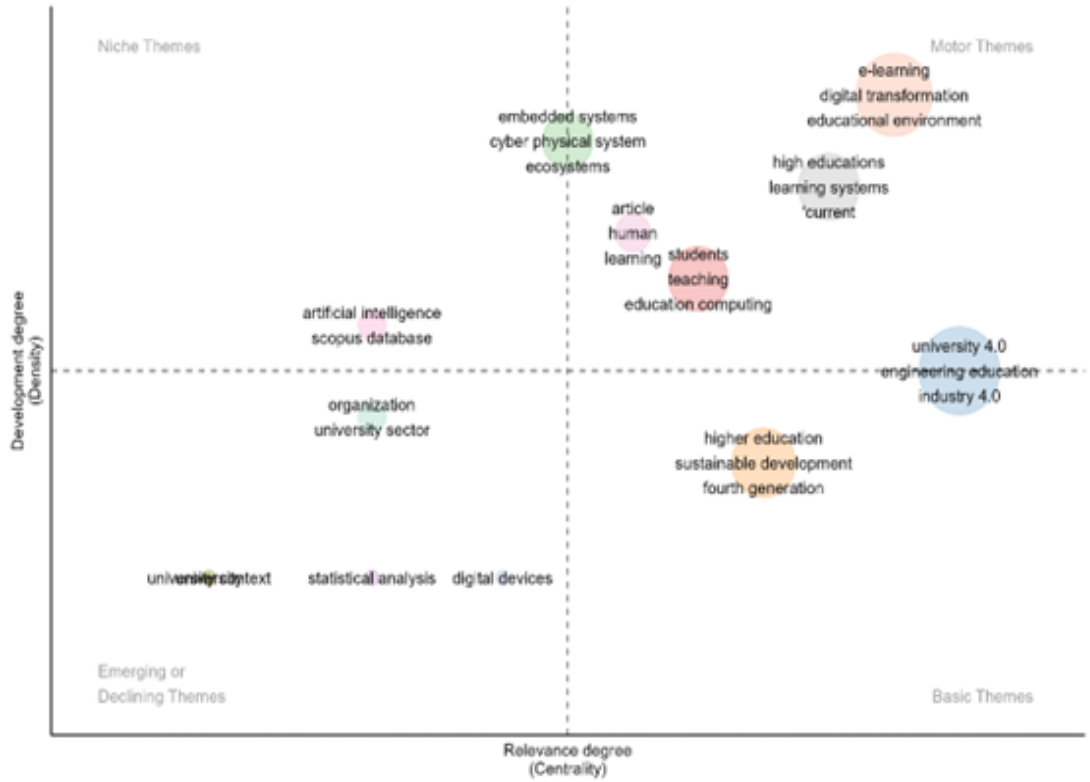
Niche themes including cyber physical systems and embedded systems—represent more specialized areas that attract focused but limited attention.

Basic themes, such as University 4.0 and Industry 4.0, form the conceptual backbone of the field and serve as reference points for much of the research.

Emerging or declining themes including digital devices and statistical analysis, show lower density or shifting levels of interest.

Taken together, this thematic structure helps clarify how different research strands evolve and how they contribute to the broader development of University 4.0 scholarship.

Fig (9): Thematic Map of University 4.0 Research



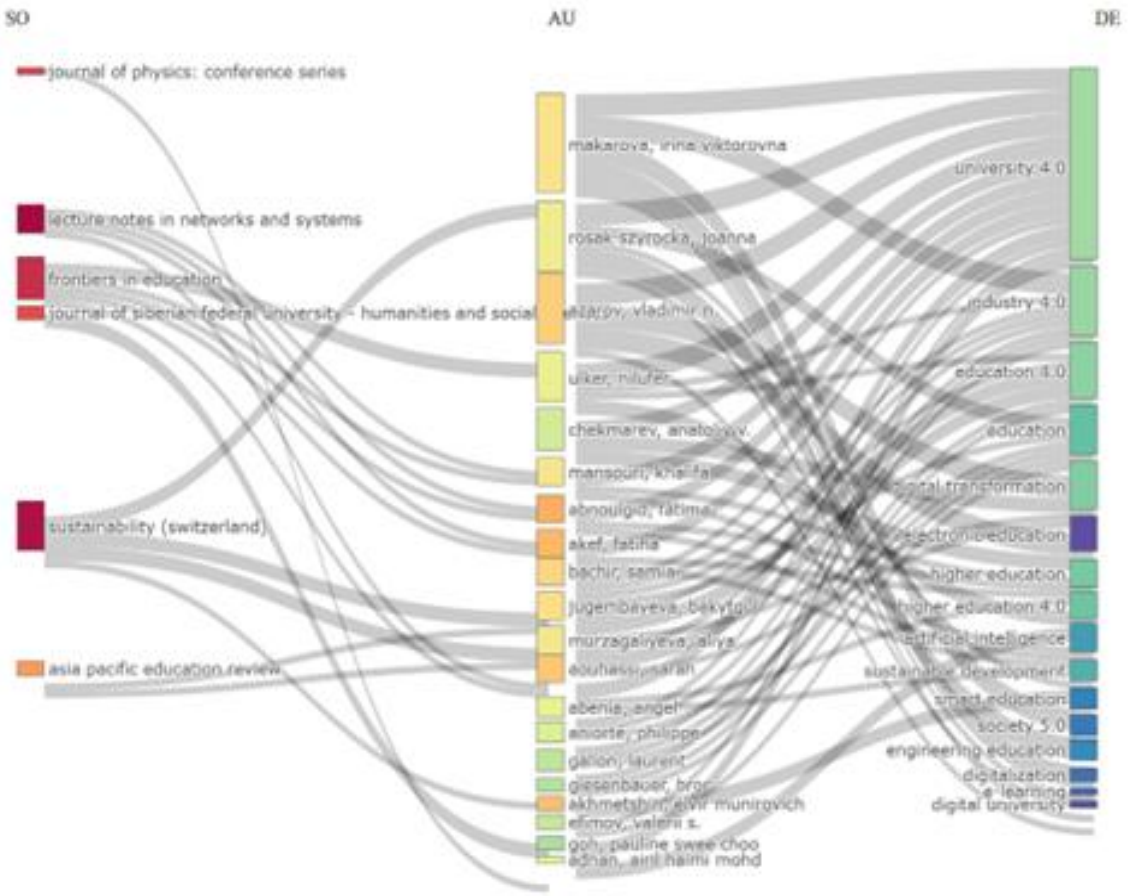
Source: Generated by the authors using Bibliometrix R package.

4.4. Intellectual and Thematic Linkages

The three field plot in Fig. 10 provides an overview of how publication sources, authors, and keywords are linked within the University 4.0 research landscape. Journals such as *Sustainability (Switzerland)*, *Lecture Notes in Networks and Systems*, and *Frontiers in Education* appear as key outlets that attract contributions from leading authors in the field.

The visualization also shows clear associations between influential authors and recurring themes, including "university 4.0," "industry 4.0," "education 4.0," and "digital transformation." These connections help illustrate how specific authors and publication venues shape the thematic direction of the field.

Fig (10): Three Field Plot Linking Sources (SO), Authors (AU), and Keywords (DE) in University 4.0 Research



Source: Generated by the authors using Bibliometrix R package.

5. Discussion

This bibliometric analysis offers an overview of how research on University 4.0 has taken shape and developed between 2009 and 2025. The findings help clarify not only the growth of this field, but also the geographic, thematic, and intellectual dynamics that have guided its evolution within the broader context of digital transformation in higher education.

5.1. Evolution and Geographic Patterns

The evolution of publications shows a marked increase after 2018, a trend that aligns with global progress in Industry 4.0 technologies and the rapid digital transformation that followed the COVID 19 pandemic. This trend aligns with the findings of Giesenbauer and Müller-Christ (2020), who noted that Industry 4.0 places significant pressure on universities to rethink their structures and adopt more flexible and multidimensional organizational models.

From a geographical perspective, the field is driven largely by emerging economies, with Russia, Morocco, Kyrgyzstan, Malaysia, and Kazakhstan appearing as central contributors. This pattern reflects a growing emphasis on digital modernization and smart university initiatives across these regions. As shown by Kerroum et al. (2020) in their analysis of Hassan

II University of Casablanca, institutions in these countries are increasingly integrating Industry 4.0 principles in shaping academic programs and governance reforms.

These efforts highlight the role of University 4.0 as an important component of national strategies aimed at strengthening higher education and supporting broader development goals.

5.2. Thematic Structure and Intellectual Foundations

The thematic clusters indicate that University 4.0 research has evolved into a broad and maturing field. Foundational themes such as University 4.0, digital transformation, and Industry 4.0 form the core conceptual base, while more developed themes such as learning systems, elearning, and smart education reflect the growing emphasis on competency based and technology supported learning, as noted by Chernaya et al. (2023).

Beyond technological aspects, the field increasingly incorporates wider institutional and societal considerations. Several highly cited studies published in *Sustainability* highlight the connection between University 4.0 and sustainability-oriented transformation, aligning with the arguments of Rosak Szyrocka et al. (2022) regarding the role of universities in advancing Society 5.0. This indicates that University 4.0 is conceptualized not merely as a technological shift but also as a pathway for rethinking governance models and strengthening the societal mission of higher education.

5.3. Collaboration Patterns and Development Gaps

The co-authorship analysis shows that collaborations remain largely regional, with limited global integration. This indicates that University 4.0 research is still forming its international networks, leaving space for wider cross-country partnerships.

Although the field is strongly rooted in engineering education and digital technologies, fewer studies address organizational change, leadership, or socio-cultural aspects. Expanding research in these areas would provide a more balanced understanding of University 4.0, in line with the human centered perspectives noted by Rosak Szyrocka et al. (2022).

The thematic patterns also suggest that some topics remain insufficiently developed, particularly regarding cyber physical systems in educational contexts, which call for further empirical and theoretical work.

6. Conclusion

In conclusion, this bibliometric analysis traces how “University 4.0” has progressed from an emerging idea to a more mature and multidisciplinary area of research. The conceptual structure reveals a central emphasis on harnessing digital technologies to facilitate and enhance learning. At the same time, the thematic map shows clear signs of maturation, with well-established motor themes such as learning systems and sustainability alongside the early development of more specialized niche themes, including cyber physical systems.

Collectively, the results offer clear answers to the research questions and outline the field’s developmental trajectory.

Practical Recommendations

Based on the findings of this study, several practical recommendations can be offered for key stakeholders.

For Policymakers and Institutional Leaders

- Develop coherent national strategies: Governments should establish clear policies to guide the transition toward University 4.0, including investment in digital infrastructure—such as smart classrooms, online learning platforms, and cybersecurity systems—and support large scale professional development for faculty.
- Strengthen industry–university collaboration: Closer partnerships with industry, in line with Helix based models, can help align academic programs with labor market needs, support the co design of curricula, and enable applied learning through joint training initiatives and real world capstone projects.
- Adapt successful regional models: Countries at earlier stages of digital transformation, such as Algeria, can draw lessons from the leading examples identified in this study (e.g. Russia and Malaysia) and tailor these frameworks to their national and institutional contexts.

For Researchers and Academics

- Address underexplored themes: Future research should engage more deeply with the niche and emerging themes identified in the thematic map, including cyber physical systems in campus operations, the use of AI in assessment, and ethical considerations surrounding data and learning analytics.
- Strengthen qualitative and field-based research: More case studies and field investigations are needed to assess how University 4.0 initiatives perform in practice and to better understand the organizational, cultural, and leadership challenges that shape implementation.
- Expand international collaboration: The observed fragmentation in co-authorship networks highlights the value of broader international cooperation. Increased collaboration especially among the most active countries could facilitate knowledge sharing and support comparative research on different implementation models.

Overall, this study provides a foundation for further advancing both theoretical and empirical work on University 4.0 and offers guidance for policymakers, institutions, and researchers working to shape the future of higher education in the digital era.

7. Limitations and Future Research

Although this study offers a structured and comprehensive bibliometric overview of the University 4.0 research domain, several limitations should be considered when interpreting the findings.

First, the search strategy was deliberately confined to the keywords *"University 4.0," "Higher Education 4.0,"* and *"Fourth Generation University."* This narrow focus helped maintain conceptual clarity but may have excluded studies addressing related ideas under different labels such as *"Smart University," "Digital University,"* or *"Education 4.0."* As a result, while the dataset reliably captures research explicitly using the University 4.0 terminology, it does not encompass the full spectrum of digital transformation literature in higher education.

Second, the analysis relied solely on the Scopus database. Although Scopus is one of the most extensive and reputable indexing platforms, relevant publications indexed in other sources—such as Web of Science, ERIC, or Google Scholar—may have been missed, introducing a degree of database selection bias.

Third, this study included only English-language publications. This may have excluded substantial contributions originating from regions where digital transformation in higher education is active but documented primarily in other languages.

Fourth, bibliometric methods depend heavily on the accuracy and consistency of metadata. Variations in author names, affiliations, keywords, or citation records within Scopus can subtly affect network structures and, consequently, the conclusions drawn from them.

Finally, the dataset covers publications up to 2025. Because the records for 2024 and 2025 were still incomplete at the time of data extraction (November 2025), the apparent decline in publication output for 2025 reflects partial coverage rather than a genuine decrease in research activity.

Building on these considerations, future research may pursue several directions:

- **Broaden search strategies** by incorporating alternative terms and related concepts to capture a more complete picture of digital transformation in higher education.
- **Include multiple databases** and extend coverage to non-English publications to minimize selection bias and enhance global representation.
- **Conduct qualitative or mixed-methods studies**, such as case studies and systematic reviews, to complement bibliometric insights with deeper contextual understanding.
- **Explore emerging themes**, including cyber-physical systems, AI-driven assessment tools, and institutional challenges related to digital transformation.
- **Investigate socio-cultural, ethical, and leadership dimensions**, which were less visible in the current analysis but remain critical for understanding University 4.0 implementation.
- **Perform longitudinal analyses** to monitor thematic shifts and collaboration patterns beyond 2025, providing a dynamic view of the field's development over time.

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