INTERNATIONAL JOURNAL OF ACADEMIC RESEARCH IN PROGRESSIVE EDUCATION & DEVELOPMENT

OPEN ACCESS JOURNAL

Vol 14, Issue 4, (2025) E-ISSN: 2226-6348

Higher Education with the Fourth Industrial Revolution: A Bibliometric Exploration of Global Research Trends

Shah Nazim Shahar[a], Abdul Hayy Haziq Mohamad[b,c], & Rossazana Ab-Rahim[b]

[a]Community College, Ministry of Higher Education, Sarawak, Malaysia, [b]Faculty of Economics and Business, Universiti Malaysia Sarawak, Sarawak, Malaysia, [c]School of Business and Management, University of Technology Sarawak, Sarawak, Malaysia

Corresponding Author Email: shahnazim@kkkg.edu.my

DOI Link: http://dx.doi.org/10.6007/IJARPED/v14-i4/26621

Published Online: 08 October 2025

Abstract

The rapid advancement of Industry 4.0 technologies has prompted significant transformations in higher education, yet scholarly engagement with this intersection remains fragmented. This study conducts a comprehensive bibliometric analysis of 266 Scopus-indexed publications from 2016 to 2025 to map the intellectual structure, thematic evolution, and citation trends of research on higher education in the context of the Fourth Industrial Revolution. Key findings reveal a steady increase in research output, peaking in 2023, with dominant contributions emerging from disciplines such as computer science, engineering, and social sciences. Thematic analysis identified core research clusters including digital learning, curriculum reform, institutional transformation, and the integration of advanced technologies such as artificial intelligence and virtual reality. Keyword evolution mapping shows a progression from early emphasis on e-learning tools toward systemic digital transformation and employability-focused educational models. While the field has matured, the results highlight a limited integration of sustainability, policy frameworks, and ethical concerns. This study not only synthesises past and current research trends but also proposes future research directions aimed at enhancing the alignment of educational innovation with the evolving demands of Industry 4.0.

Keyword: Bibliometric, Digital Learning, Higher Education, Industry 4.0, Technology

Introduction

The acceleration of technological innovation in recent years has ushered in the Fourth Industrial Revolution, widely known as Industry 4.0. Driven by the integration of artificial intelligence, the Internet of Things, robotics, and big data analytics, this transformation is reshaping the global economic landscape and redefining the nature of social interaction (Vermesan et al., 2022; Kumar et al., 2024; Van Hoang, 2024). According to Klingenberg et al. (2022) and Veile et al. (2022), beyond revolutionising industry and commerce, Industry 4.0 is

altering the ways in which knowledge is created, shared, and applied across various sectors. As the boundaries between the physical, digital, and biological realms become increasingly intertwined, societies are confronted with both significant opportunities and complex challenges (Krishna, 2024; Bibri, 2022; Vanderhorst et al., 2024).

In this evolving context, institutions involved in education and research are expected to adapt and remain responsive to the demands of digital transformation. Higher education systems, in particular, occupy a central role in preparing future-ready graduates, cultivating digital literacy, and driving national innovation. While much of the global discourse has focused on the implications of Industry 4.0 for productivity, automation, and economic competitiveness, its impact on higher education is equally profound (Mian et al., 2020; Tri et al., 2021; Yang, 2023). Universities are now expected to move beyond their traditional roles as centres of academic knowledge and assume more dynamic functions as drivers of innovation, enablers of digital competence, and contributors to workforce readiness in a rapidly transforming global environment.

This paradigm shift has led to the emergence of the term “Education 4.0” (Bonfield et al., 2020; Mansor et al., 2020; Moraes et al., 2023), which reflects the urgent need for education systems to become more agile, learner-centred, and aligned with the digital economy (Bonfield et al., 2020; Costan et al., 2021). Despite the growing attention to this concept, the academic response to the challenges and opportunities presented by Industry 4.0 remains uneven and fragmented. A critical concern is the widening gap between the rapid pace of technological change and the slower responsiveness of higher education institutions (Mubarak & Petraite, 2020; Sharma et al., 2021; Awan et al., 2022). As noted by Wawak et al. (2024), Salvador et al. (2023), and Fahim et al. (2021), many universities face difficulties in updating curricula, refining pedagogical methodologies, and reformulating institutional strategies to align with the evolving needs of Industry 4.0. This disconnection raises important questions about the capacity of higher education to support national innovation strategies, enhance graduate employability, and promote inclusive access to digital learning.

This issue is further compounded by the lack of comprehensive empirical evidence that maps how researchers across disciplines, regions, and time periods have engaged with the educational dimensions of the Fourth Industrial Revolution. To address this gap, the present study applies bibliometric analysis to 266 Scopus-indexed publications from 2016 to 2025 that focus on the intersection of higher education and Industry 4.0. There are 5 objectives will be cover in this study:

1. To analyse publication and citation trends on higher education and Industry 4.0 from 2016 to 2025.
2. To identify dominant disciplines in higher education and Industry 4.0 studies.
3. To evaluate author productivity, collaboration, and citation impact in higher education and Industry 4.0 studies.
4. To map thematic structures and trace the evolution of key research themes in higher education and Industry 4.0 studies.
5. To identify future research directions by analysing thematic evolution, colour cluster network, and overlay of the occurrences keywords in higher education and Industry 4.0 studies.

This study contributes to the social science literature by offering the first comprehensive bibliometric analysis of global research on higher education and Industry 4.0 over the 2016–2025 period. By mapping publication trends, thematic evolution, and collaboration patterns, the study provides empirical evidence on how academic communities have conceptualised and responded to the educational challenges of digital transformation. The findings are expected to guide policymakers, researchers, and university leaders in shaping strategic responses to Industry 4.0 within the broader social science framework.

Literature Review

Bibliometric analysis has increasingly been recognised as a rigorous methodological tool for systematically exploring the evolution, structure, and thematic progression of educational research. Through quantitative techniques such as citation analysis, co-word mapping, and science mapping, bibliometric studies provide valuable insights into the impact of research, the emergence of thematic clusters, and the identification of key contributors. Recent literature has demonstrated the utility of bibliometric approaches in tracing the advancement of educational technologies, pedagogical practices, and institutional quality assessment.

A study by Sánchez et al. (2022) conducted a comprehensive bibliometric study on the integration of virtual reality (VR) in educational contexts. By drawing data from Scopus and Web of Science, their analysis revealed growing academic interest in immersive learning environments. The study identified active learning and human-computer interaction as the most prominent themes, suggesting that VR is becoming a significant pedagogical tool that supports experiential and student-centred learning.

Similarly, Guerrero et al. (2020) focused on artificial intelligence (AI) in education, employing co-word analysis and traditional bibliometric indicators such as the h-index and g-index. Their findings highlighted an increasing number of publications addressing AI applications in personalised learning, academic assessment, and educational administration. The study also identified leading institutions and influential publications, underlining AI's transformative potential within educational settings. The emphasis on ethical and pedagogical frameworks in their analysis reflects a growing awareness of the complexities involved in integrating intelligent systems into the classroom.

In support of Guerrero et al. (2020), the bibliometric review by Hinojo-Lucena et al. (2019) analysed the academic discourse on AI in higher education, with a particular emphasis on virtual tutoring systems. The study revealed a steady increase in citations related to AI-assisted instruction, confirming the expanding role of AI technologies in enhancing student engagement and learning efficiency. These findings reinforce the notion that AI is playing a central role in redefining contemporary educational practices.

In a different thematic direction, Brika et al. (2021) examined how bibliometric tools are used to assess the quality of higher education. Their study revealed a growing reliance on citation-based metrics and software tools to evaluate academic productivity and institutional performance. By correlating research output with educational outcomes, the study highlighted the potential of bibliometric analysis in guiding quality assurance practices and policy development in the higher education sector.

There also study focusing on student interaction and institutional efficiency, Chamorro-Atalaya et al. (2023) conducted a bibliometric analysis of chatbot applications in university education. Their review of 210 manuscripts demonstrated that conversational agents are increasingly integrated into administrative and student support services. This trend reflects a broader technological acceptance within higher education institutions, aligning with the findings of Sánchez et al. (2022) regarding VR adoption. Both studies emphasise the importance of digital tools in supporting both instructional and non-instructional functions.

From a longitudinal perspective, Okagbue et al. (2023) offered an extensive bibliometric review covering 21 years of AI and machine learning research in education. Their work charted the historical development of the field, from early algorithmic applications to more recent pedagogical innovations. The study demonstrated the continuity and evolution of AI-related educational research, highlighting how current technological developments build upon earlier foundational work. In a similar vein, Chamorro-Atalaya et al. (2024) examined the role of digital twin technology in higher education. Their bibliometric findings suggest that digital twins offer innovative ways to replicate real-world learning environments through simulation. The study proposed that such technologies can improve engagement and learning outcomes while supporting institutional goals related to sustainability and operational efficiency.

Prieto-Jiménez et al. (2021) explored how education aligns with the Sustainable Development Goals (SDGs), using science mapping to visualise thematic connections across research areas. Their findings revealed that technological initiatives such as AI and VR are increasingly framed within the discourse on sustainability, reflecting an integrative approach to educational transformation. This connection is further supported by Veres et al. (2025), who synthesised emerging trends in sustainability-related educational research. Their study provided a roadmap for educational institutions aiming to incorporate sustainability into both operational strategies and instructional practices.

Bibliometric methods have proven valuable in mapping research trends in higher education, particularly in digital transformation, sustainability, and pedagogy. However, there is limited integration of these themes within the broader context of Industry 4.0. This gap highlights a novel direction for future bibliometric research to explore the convergence of higher educational and Industry 4.0.

Methodology

Research Design and Purpose

This study applies a quantitative bibliometric approach to systematically examine the scholarly landscape at the intersection of higher education and Industry 4.0. Bibliometric analysis enables the identification of publication trends, influential authors, intellectual structures, and evolving research themes (Brika et al., 2021; Mohamad et al., 2024a). This method is particularly suited for evaluating large volumes of scientific literature and for mapping the development of emerging interdisciplinary fields.

Topic, Scope, and Eligibility

The scope of the analysis focuses on literature that explores how higher education systems—including technical and vocational education and training (TVET)—are transforming in

response to the technological paradigms of Industry 4.0. The inclusion criteria were broad and inclusive: all document types (journal articles, conference proceedings, book chapters, and reviews) indexed in the Scopus database were considered, with no restriction on publication year, language, or subject category. However, it is noteworthy that the earliest document retrieved was published in 2016, indicating that scholarly attention to this intersection only began to gain visibility from that year onward.

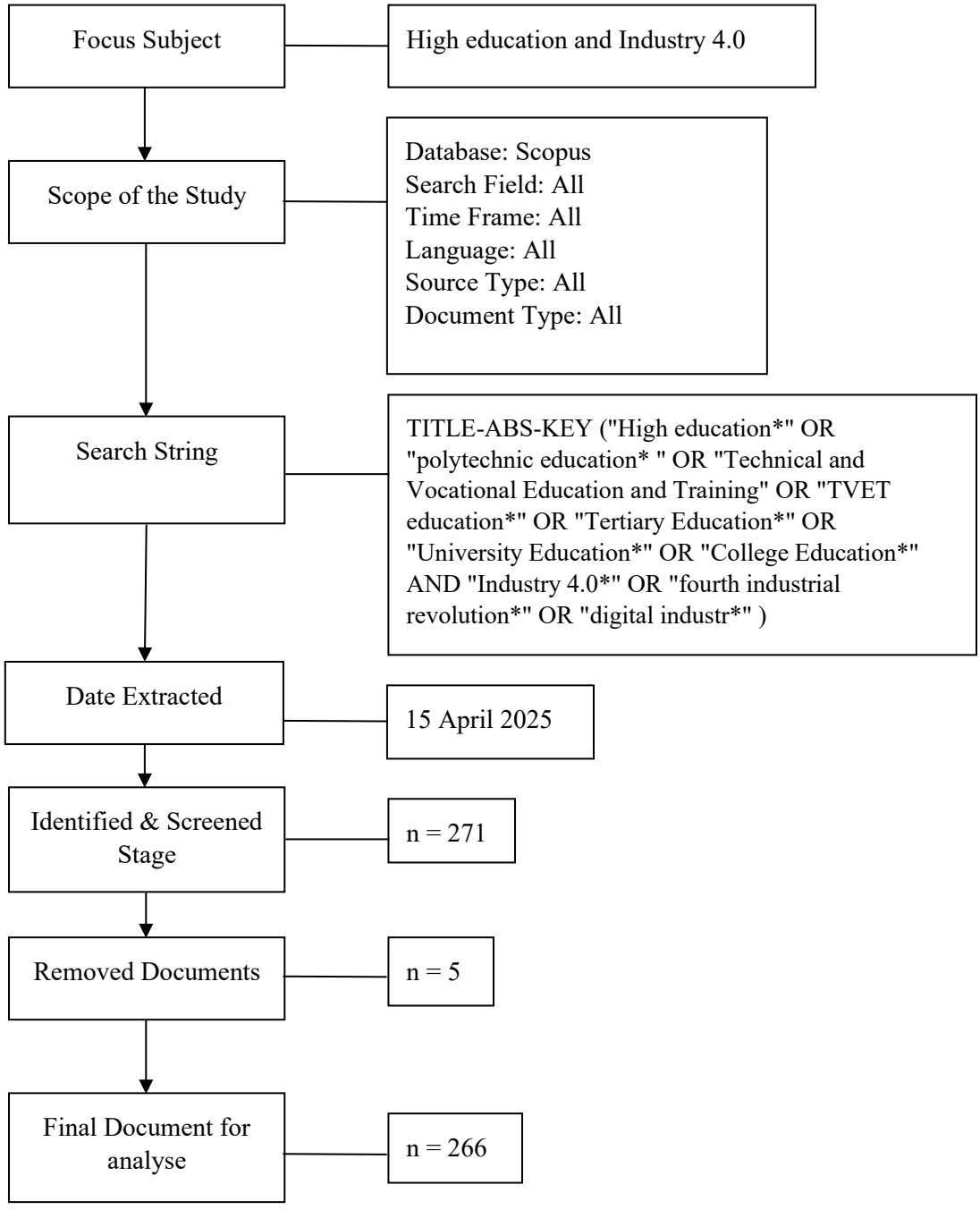

Figure 1. Flow diagram of the search strategy.

Data Source and Search Strategy

Figure 1 present this study were retrieved from the Scopus database, chosen for its extensive indexing of peer-reviewed and high-impact scientific publications across multiple disciplines. The search was performed on 15 April 2025 using the following research string:

TITLE-ABS-KEY ("High education*" OR "polytechnic education*" OR "Technical and Vocational Education and Training" OR "TVET education*" OR "Tertiary Education*" OR "University Education*" OR "College Education*") AND ("Industry 4.0*" OR "fourth industrial revolution*" OR "digital industr*")

This search strategy was designed to capture relevant literature by combining broad educational terms with concepts associated with Industry 4.0, using wildcard characters to account for suffix variations.

Data Extraction and Cleaning

The initial search yielded a total of 271 documents. Bibliographic metadata—including titles, abstracts, authors, affiliations, keywords, publication years, source titles, and citation counts—were exported in CSV and Scopus refine file formats.

To ensure data quality, a structured cleaning process was conducted using OpenRefine, an open-source tool widely employed in bibliometric studies. OpenRefine was used to detect and remove duplicate entries, standardise inconsistent spellings and formatting of author names, institutional affiliations, and keywords, and also ensure uniformity in metadata prior to analysis (Mohamad et al., 2024a; Huang et al., 2020). During the screening process, five documents were removed because they were found to be thematically irrelevant which also did not address higher education or Industry 4.0 substantively, or used the keywords in unrelated contexts. After cleaning and screening, a final dataset of 266 documents was retained for bibliometric analysis.

Analytical Tools and Techniques

The cleaned dataset was analysed using a suite of complementary software tools:

- Microsoft Excel was used for preliminary tabulation, manual validation of data entries, and generation of descriptive statistics such as publication trends.
- OpenRefine played a crucial role in cleaning and normalising metadata to eliminate inconsistencies that could affect analysis outcomes.
- VOSviewer was employed for constructing and visualising bibliometric networks, including co-authorship, keyword co-occurrence, institutional collaboration, and citation mapping.
- R software, particularly the Bibliometrix package and its graphical interface Biblioshiny, was used for comprehensive bibliometric and science mapping analysis. Of particular importance, Biblioshiny was used to conduct the thematic evolution analysis, which allowed the identification of how research themes emerged, matured, or declined across different time periods.

These tools complemented one another in enabling both the quantitative and visual interpretation of bibliographic patterns, thereby offering a holistic view of the intellectual and thematic structure of the field (Mohamad et al., 2024b; Sánchez et al., 2022; Veres et al., 2025).

Result and Discussions

Table 1

Main Information

Main Information	Data
Publication Years	2016 - 2025
Total Publications	266
Citable Year	10
Number of Contributing Authors	883
Number of Cited Papers	164
Total Citations	2,102
Citation per Paper	7.90
Citation per Cited Paper	12.82
Citation per Year	233.56
Citation per Author	2.38
Author per Paper	3.32
Citation sum within h-Core	1,796
h-index	19
g-index	40
m-index	1.90

Table 1 presents the core bibliometric indicators derived from publications related to higher education and Industry 4.0 between 2016 and 2025. Over the ten-year period, a total of 266 publications were recorded, with contributions from 883 unique authors. This indicates active and growing interest in the field, supported by a broad base of researchers. Out of all the documents analysed, 164 were cited at least once, representing approximately 61.7% of the total output. The cumulative citation count reached 2,102, resulting in an average of 7.90 citations per publication. For those papers that were cited, the average citation rate rose to 12.82, suggesting a high level of influence among the more impactful studies. The average number of citations per year stood at 233.56, reflecting consistent scholarly engagement with the topic.

In terms of authorship patterns, the average number of authors per paper was 3.32, highlighting moderate levels of collaboration, which are typical in interdisciplinary studies bridging education, technology, and industrial innovation. Each author, on average, received 2.38 citations, implying a balanced distribution of academic impact across contributors. The citation structure reveals a strong core of influential work. A total of 1,796 citations, which mean that around 85% of all citations are concentrated within the h-core. The h-index of 19 demonstrates that 19 papers have each garnered at least 19 citations, while the g-index of 40 signifies that the top 40 publications collectively received at least 1,600 citations. Additionally, the m-index of 1.90 indicates steady annual growth in the research impact since the field began developing around 2016.

Table 2
Subject Area

Subject Area	Total Publication	Percentage (%)
Computer Science	141	53.01
Engineering	121	45.49
Social Sciences	111	41.73
Decision Sciences	36	13.53
Business, Management and Accounting	31	11.65
Mathematics	26	9.77
Economics, Econometrics and Finance	16	6.02
Energy	14	5.26
Materials Science	11	4.14
Physics and Astronomy	11	4.14

Table 2 illustrates the disciplinary spread of publications on higher education and Industry 4.0. The analysis shows that the research is primarily concentrated in the domains of Computer Science (53.01%), Engineering (45.49%), and Social Sciences (41.73%). This indicates a strong technological orientation in the literature, reflecting the pivotal role of digital technologies, automation, and technical infrastructure in shaping educational transformations aligned with the Fourth Industrial Revolution (Omodan, 2024; Kumar et al., 2024).

The significant contribution from the Social Sciences underscores the importance of understanding pedagogical, institutional, and societal dimensions in the integration of Industry 4.0 concepts into educational systems. Notably, fields such as Decision Sciences (13.53%) and Business, Management and Accounting (11.65%) also feature prominently, highlighting the growing emphasis on data-driven decision-making, strategic planning, and organisational adaptation within educational contexts.

Other contributing disciplines include Mathematics (9.77%), Economics, Econometrics and Finance (6.02%), and Energy (5.26%), reflecting the interdisciplinary nature of the research area. Although their representation is relatively modest, domains such as Materials Science (4.14%) and Physics and Astronomy (4.14%) suggest that some research also explores advanced technologies and applied sciences in relation to technical and vocational education. The breadth of subject areas represented in the literature confirms that the interface between higher education and Industry 4.0 is not confined to a single academic domain, but instead requires cross-sectoral knowledge and multi-disciplinary collaboration to effectively address the complexity of digital transformation in education.

Table 3
Language

Language	Total Publication	Percentage (%)
English	260	97.74
Spanish	6	2.26
Chinese	1	0.38
Russian	1	0.38

The analysis of publication language, summarised in Table 3, reveals a strong dominance of English-language contributions, which account for 97.74% (260 out of 266 publications). This overwhelming prevalence reflects the global trend of English serving as the primary medium for scholarly communication (Lillis and Curry, 2006), particularly in fields that intersect technology, education, and international development.

The remaining publications were authored in Spanish (2.26%), with one publication each in Chinese (0.38%) and Russian (0.38%). The limited presence of non-English publications suggests that while the topic garners international attention, the discourse is largely centralised within English-speaking academic circles. This may pose challenges for knowledge accessibility and cross-cultural integration, particularly in regions where English is not the primary language of instruction. Nonetheless, the inclusion of works in Spanish, Chinese, and Russian indicates a growing but modest level of international engagement, pointing to the need for broader linguistic inclusivity and regional collaboration in the study of higher education and Industry 4.0.

Table 4
Trend Publication

Year	TP	NCP	TC	C/P	C/CP	h-index	g-index
2016	2	1	7	3.50	7.00	1	2
2017	6	4	210	35.00	52.50	3	6
2018	8	8	66	8.25	8.25	5	8
2019	23	23	238	10.35	10.35	9	15
2020	20	15	380	19.00	25.33	9	19
2021	36	27	151	4.19	5.59	8	9
2022	42	32	678	16.14	21.19	11	25
2023	63	32	267	4.24	8.34	6	15
2024	49	20	103	2.10	5.15	5	9
2025	17	2	2	0.12	1.00	1	1

Notes: TP=total number of publications; NCP=number of cited publications; TC=total citations; C/P=average citations per publication; C/CP=average citations per cited publication; h=h-index; and g=g-index.

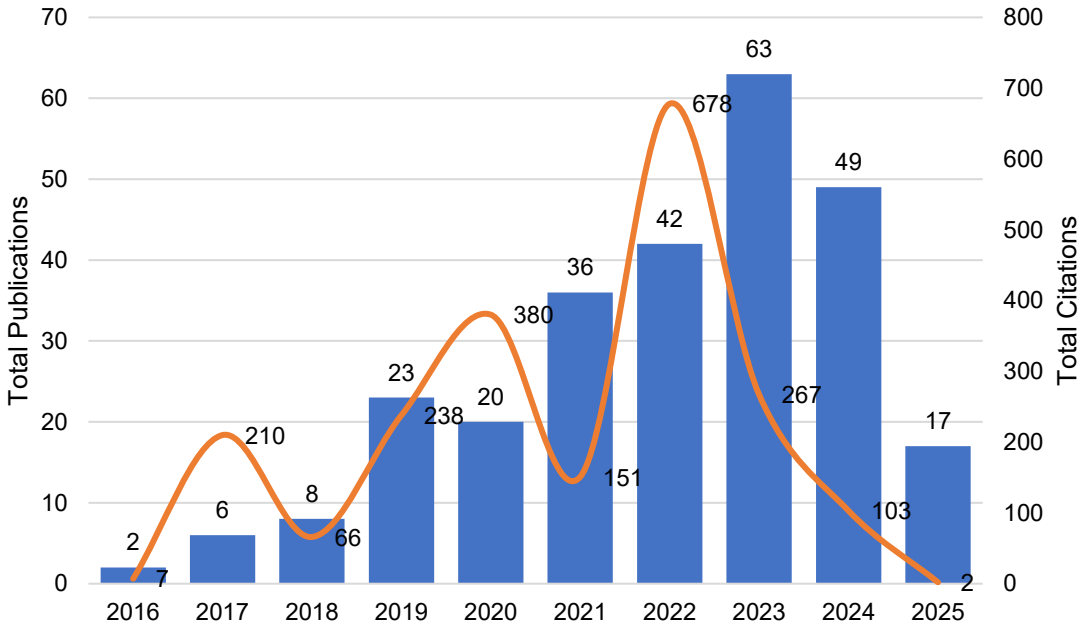

Figure 2. Publication and Citations
*Note: Although the search query included all publication years, the earliest record identified was from 2016, marking the starting point of academic attention to this topic.

Table 4 and Figure 2 presents the annual publication trends and citation performance of documents published between 2016 and 2025. The analysis reveals both quantitative growth in publication output and fluctuations in scholarly impact over time, offering insight into the maturity and influence of the field.

From an initial 2 publications in 2016, the annual output rose consistently, peaking at 63 publications in 2023. This growth reflects increasing scholarly interest in the convergence between higher education and Industry 4.0, particularly in response to global events and technological disruption. The rapid expansion in 2022 and 2023 corresponds with a post-pandemic research surge, likely driven by the need to rethink educational delivery systems and technological integration. Although there is a slight decline in 2024 (49 papers) and a further drop in 2025 (17 papers, partial year), the overall trend demonstrates a substantial and sustained increase in research productivity over the decade. The field's citation dynamics reveal important shifts in influence. The most impactful year in terms of total citations was 2022, with 678 citations, followed by 2020 with 380 citations. Both years also recorded high values for citations per paper (C/P) and citations per cited paper (C/CP), indicating that research published during these periods had a strong and immediate scholarly uptake.

The year 2017 is particularly notable and despite having only 6 publications, it achieved 210 total citations, averaging 35 citations per paper, the highest across the entire period. This suggests that seminal or pioneering works published during the early years of the Industry 4.0 discourse had a disproportionate influence on subsequent literature. In contrast, recent years (2023–2025) exhibit lower citation metrics, which is expected due to the shorter citation window. For example, publications in 2024 averaged 2.10 citations per paper, and in 2025, the average is only 0.12, given that these works are still in the process of accumulating citations.

The h-index and g-index values follow a similar trajectory, peaking in 2022 (h = 11, g = 25) and 2020 (h = 9, g = 19), reflecting both quantity and depth of impact. These metrics confirm that 2020–2022 represents the most productive and influential period of research in this domain. Recent years (2023 onward) have recorded moderate h and g-index values, suggesting that while research output remains high, the long-term impact of these contributions is still evolving.

Table 5. 10
Most Cited Research

No.	Author(s)	Title	Source Title	TC	C/Y
1	Broo D. G.; Kaynak O.; Sait S.M. (2022)	Rethinking engineering education at the age of industry 5.0	Journal of Industrial Information Integration	258	64.50
2	Mhlanga D.; Moloi T. (2020)	COVID-19 and the digital transformation of education: What are we learning on 4ir in South Africa?	Education Sciences	235	39.17
3	Motyl B.; Baronio G.; Uberti S.; Speranza D.; Filippi S. (2017)	How will Change the Future Engineers' Skills in the Industry 4.0 Framework? A Questionnaire Survey	Procedia Manufacturing	195	21.67
4	Okunlaya R.O.; Syed Abdullah N.; Alias R.A. (2022)	Artificial intelligence (AI) library services innovative conceptual framework for the digital transformation of university education	Library Hi Tech	151	37.75
5	Dai Y.; Liu A.; Lim C.P. (2023)	Reconceptualizing ChatGPT and generative AI as a student-driven innovation in higher education	Procedia CIRP	133	44.33
6	Malomane R.; Musonda I.; Okoro C.S. (2022)	The Opportunities and Challenges Associated with the Implementation of Fourth Industrial Revolution Technologies to Manage Health and Safety	International Journal of Environmental Research and Public Health	43	10.75
7	Haderer B.; Ciolacu M. (2022)	Education 4.0: Artificial Intelligence Assisted Task- and Time Planning System	Procedia Computer Science	35	8.75
8	Pauceanu A.M.; Rabie N.; Moustafa A. (2020)	Employability under the fourth industrial revolution	Economics and Sociology	34	5.67
9	George W.K.; Silas E.I.; Pandey D.; Pandey B.K. (2024)	Utilization of industry 4.0 technologies in Nigerian technical and vocational education: A conundrum for educators	Examining the Rapid Advance of Digital Technology in Africa	33	16.50
10	Telukdarie A.; Munsamy M. (2019)	Digitization of Higher Education Institutions	IEEE International Conference on Industrial Engineering and Engineering Management	32	4.57

TC=total citations; C/Y= Cited per year

Table 5 highlights the ten most cited documents in the field, showcasing key contributions that have significantly influenced the academic discourse at the intersection of higher education and Industry 4.0. The most highly cited article is Broo et al. (2022), titled *"Rethinking Engineering Education at the Age of Industry 5.0"*, published in the *Journal of Industrial Information Integration*, with 258 citations and an average of 64.5 citations per year. This work repositions the educational paradigm beyond Industry 4.0 by emphasising human-centric and sustainable approaches under the emerging Industry 5.0 framework. Its high citation rate reflects growing interest in future-ready education that integrates ethical and social considerations alongside technological innovation.

In second place, Mhlanga and Moloi (2020) explore *"COVID-19 and the Digital Transformation of Education"* in *Education Sciences*, accumulating 235 citations (39.17 citations/year). This article is one of the earliest to critically assess how the pandemic accelerated digital learning and exposed inequalities in South Africa, offering insights that resonated globally. Third, Motyl et al. (2017) investigated evolving engineering skillsets in *Procedia Manufacturing*, garnering 195 citations. Their work remains foundational in identifying competency gaps and preparing future engineers for the digital workplace. Other influential study includes Okunlaya et al. (2022), who proposed a conceptual framework for integrating AI into university library services, receiving 151 citations, and Dai et al. (2023), whose recent work on the integration of ChatGPT and generative AI into student-driven higher education settings has already accrued 133 citations, demonstrating its timely relevance in the post-AI-acceleration era.

The remaining entries cover a diverse range of topics such as the role of 4IR technologies in occupational health and safety (Malomane et al.), AI-assisted educational tools (Haderer and Ciolacu, 2022), employability challenges in 4IR (Pauceanu et al. 2020), technology integration in TVET institutions (George et al. 2024), and digital transformation of higher education (Telukdarie and Munsamy, 2019). Although these studies have relatively fewer total citations, their average citations per year remain strong, reflecting sustained and current academic relevance. Collectively, these publications not only exhibit high academic visibility but also underscore key research themes such as digital competencies, artificial intelligence, pedagogical transformation, and institutional adaptation—all central to the educational transition in the Fourth Industrial Revolution.

Table 6
Source Title

Source Title	TP	NCP	TC	C/P	C/CP	h	g
Lecture Notes in Networks and Systems	16	4	6	0.38	1.50	1	2
ACM International Conference Proceeding Series	4	2	4	1.00	2.00	2	2
Smart Innovation, Systems and Technologies	4	1	5	1.25	5.00	1	2
Lecture Notes in Mechanical Engineering	4	3	4	1.00	1.33	1	1
AIP Conference Proceedings	3	1	2	0.67	2.00	1	1

Notes: TP=total number of publications; NCP=number of cited publications; TC=total citations; C/P=average citations per publication; C/CP=average citations per cited publication; h=h-index; and g=g-index.

An examination of the most productive source titles, presented in Table 6, reveals that research output on higher education and Industry 4.0 has been widely disseminated through conference proceedings and edited volumes, reflecting the applied and rapidly evolving nature of the field.

The most prolific source is Lecture Notes in Networks and Systems, which published 16 papers, although these works accumulated a relatively modest total of 58 citations. Among them, only 4 publications were cited, resulting in a citation per paper (C/P) of 0.38 and a citation per cited paper (C/CP) of 1.50. The low average citations per paper suggest that while this outlet is a common venue for dissemination, the academic influence of individual articles tends to be limited.

ACM International Conference Proceeding Series ranks second with 4 publications, generating 13 citations, of which 2 papers were cited. It recorded a C/P of 1.00 and C/CP of 2.00, indicating slightly higher visibility. This venue is notable for its emphasis on computer science and digital technologies, which aligns closely with Industry 4.0 themes.

Smart Innovation, Systems and Technologies, also with 4 papers, accumulated 12 citations, though only one of these publications had been cited. Interestingly, its citation per cited paper (5.00) is the highest among the listed sources, suggesting the presence of a single highly influential article within this series.

Other recurring outlets include Lecture Notes in Mechanical Engineering and AIP Conference Proceedings, each with 4 and 3 publications, respectively. Both recorded modest citation performance with h-index values of 1, reflecting limited but consistent contributions. The h-index and g-index values across these sources remain low, typically ranging from 1 to 2, further confirming that most publications in these proceedings serve more as knowledge-sharing platforms than as venues for high-impact theoretical contributions.

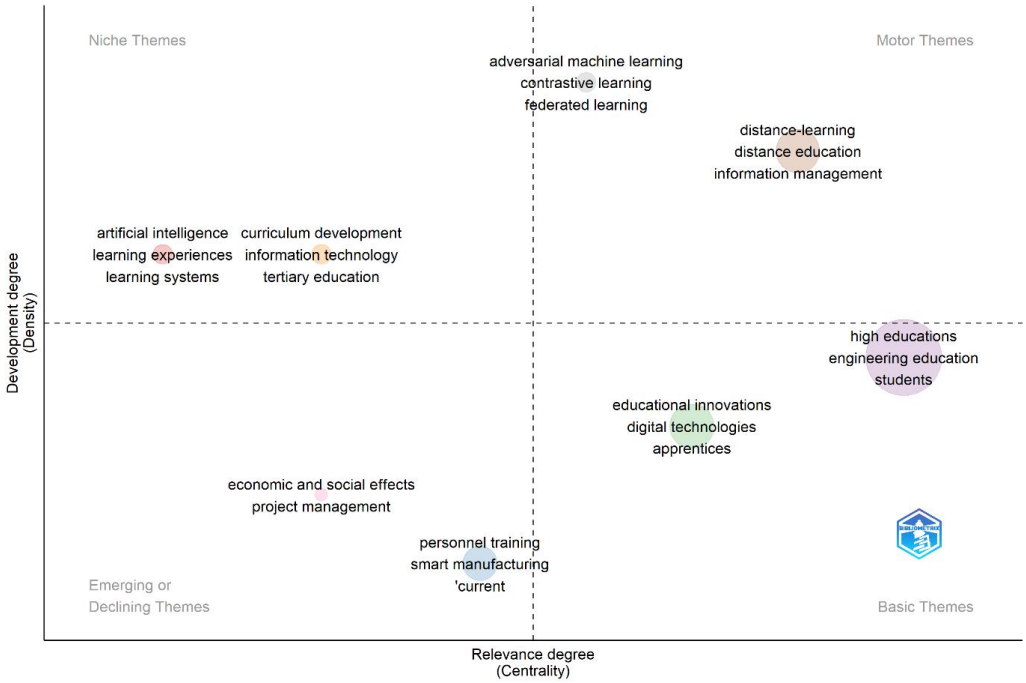

Figure 3. Thematic evolution: Mapping of Keyword Clusters

Figure 3 presents a strategic thematic map that visually delineates the structural positioning and developmental trajectory of key research themes in the domain of higher education and the Fourth Industrial Revolution (Industry 4.0). The map is structured into four quadrants based on two bibliometric dimensions which are the density (indicating internal development and coherence of the theme) and centrality (reflecting its degree of relevance and connectivity to other themes in the field).

Motor Themes (Upper Right Quadrant)

Themes located in the upper-right quadrant, categorised as Motor Themes, are characterised by both high centrality and high density. These themes are not only conceptually well-developed but also play a pivotal role within the research field due to their strong interconnections with other thematic areas. Noteworthy themes in this quadrant include *"distance learning," "distance education,"* and *"information management."* Their presence reflects the intensified global discourse surrounding the digital transformation of education, particularly accelerated by the COVID-19 pandemic (Rof et al., 2022; Mhlanga and Moloi, 2020). The conceptual maturity and relevance of these themes underscore their continued significance and likely persistence as central pillars in future research trajectories (Wei and Lin, 2024).

Basic and Transversal Themes (Lower Right Quadrant)

The lower-right quadrant houses themes of high relevance but relatively lower internal development, referred to as Basic and Transversal Themes. These represent foundational constructs that support a broad range of scholarly inquiry but are not yet deeply elaborated or internally cohesive. Dominant terms in this category include *"high educations," "engineering education,"* and *"students."* This positioning suggests that these themes serve as core conceptual anchors that integrate multiple research threads. The appearance of *"educational innovations," "digital technologies,"* and *"apprentices"* further signifies active, ongoing exploration of pedagogical reforms and the alignment of educational outcomes with labour market requirements in the context of Industry 4.0 (Piątkowski, 2020; Eberhard et al., 2017).

Niche Themes (Upper Left Quadrant)

Positioned in the upper-left quadrant are Niche Themes, which exhibit high internal density but low centrality. These are typically specialised and methodologically robust areas of inquiry that remain relatively peripheral to the mainstream research discourse. Included in this quadrant are themes such as *"artificial intelligence," "curriculum development," "learning experiences,"* and *"tertiary education."* Their strong internal cohesion reflects intensive theoretical or empirical development, however there shows the limited linkage to other themes suggests that they function within narrower scholarly communities. Nonetheless, these themes may represent emerging areas of innovation that hold potential for greater integration into broader discussions as the field continues to evolve (Veile et al., 2022; Ahmad, 2024), which particularly with regard to AI-driven educational technologies.

Emerging or Declining Themes (Lower Left Quadrant)

Themes situated in the lower-left quadrant, classified as Emerging or Declining, are characterised by low centrality and low density. These themes exhibit limited development and marginal relevance in the current literature, which may indicate either a decline in

scholarly attention or the early stages of conceptual emergence. Keywords such as *"economic and social effects," "project management," "smart manufacturing,"* and *"personnel training"* appear here. While presently underexplored, the inclusion of topics like *"smart manufacturing"* and *"personnel training"* suggests preliminary intersections between industrial automation and educational frameworks, such as in the areas that may gain prominence as technical and vocational education responds more directly to Industry 4.0 imperatives (Adel, 2024, Sharma et al., 2024).

High-Density Isolated Themes (Top-Central Zone)

A distinctive cluster situated near the upper-centre of the map includes terms such as *"adversarial machine learning," "contrastive learning,"* and *"federated learning."* These themes demonstrate high internal density but limited external connectivity, indicating technically advanced yet currently isolated research topics. This presence the emergence of experimental and computational innovations in the educational landscape, particularly within AI-related applications. According to Omodan (2024) and Raffaghelli and Sangrà 2023) the digital infrastructure of higher education institutions continues to evolve, such themes may gradually integrate into the core discourse, especially in data-intensive learning environments.

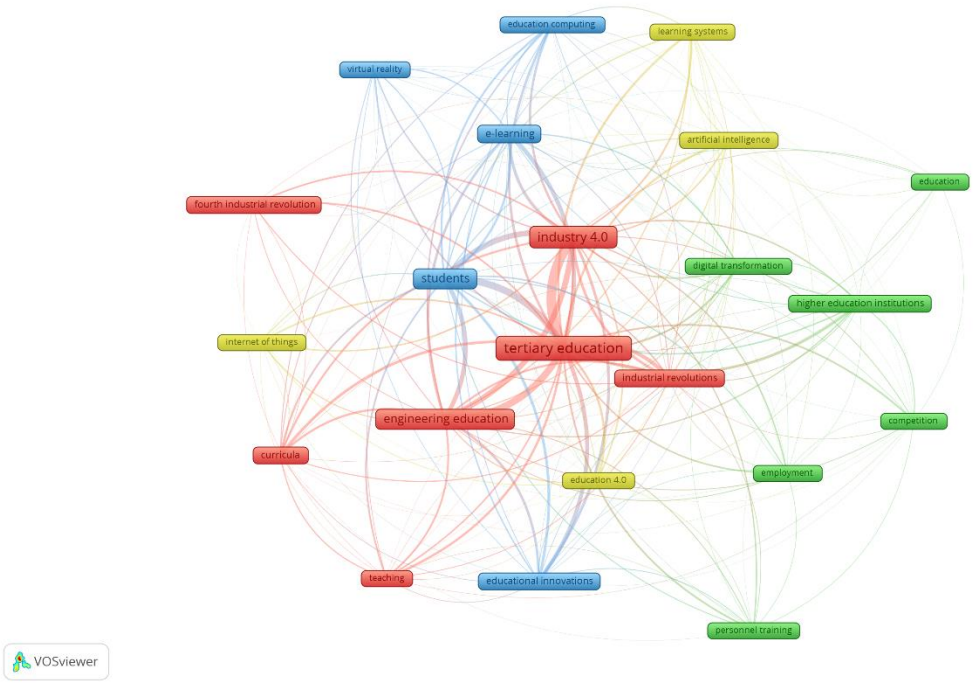

Figure 4. The "All Keyword" Co-Occurrence and Colour Cluster Analysis

Figure 4 displays the keyword co-occurrence network generated using the full counting method, wherein all occurrences of a keyword are considered in the analysis. A total of 22 keywords met the threshold of at least 12 occurrences, selected from an initial pool of 1,970 "all keywords". At the centre of the map lies the keyword "tertiary education," which is the most dominant node, signifying its pivotal role in the research landscape on Industry 4.0. This term exhibits strong co-occurrence links with "industry 4.0," "engineering education," "students," "education 4.0," and "curricula," suggesting that scholarly discussions

predominantly revolve around how tertiary-level institutions are evolving to meet the requirements of the digital and industrial transformation era.

Core Red Cluster: Industry 4.0 and Curriculum Reform

The red cluster connects "tertiary education" with "industry 4.0," "engineering education," "fourth industrial revolution," and "teaching." This cluster reflects the foundational discourse on the need for reform in curriculum content, teaching practices, and institutional strategies to equip students with skills relevant to a digitally integrated industrial environment. The dense connectivity within this group highlights that pedagogical transformation is a central theme in the Industry 4.0 discourse.

Blue Cluster: Digital Learning and Students

The blue cluster centres around "students," "e-learning," "virtual reality," and "education computing." This grouping underscores the focus on digital learning modalities, especially in response to technological shifts and post-pandemic educational delivery models. The presence of terms such as "e-learning" and "virtual reality" indicates increasing scholarly interest in immersive and remote learning experiences.

Green Cluster: Institutional and Policy Perspectives

In the green cluster, keywords such as "education," "higher education institutions," "employment," "competition," and "digital transformation" appear. This thematic area reflects a macro-level perspective, highlighting how policy, institutional roles, and labour market outcomes are integrated into the broader discussion on educational innovation. It also suggests an emphasis on the systemic role of universities and vocational institutions in supporting national and regional innovation strategies.

Yellow Cluster: Technological Foundations

A smaller but conceptually significant yellow cluster includes keywords such as "artificial intelligence," "internet of things," "learning systems," and "education 4.0." This cluster represents the technological underpinnings of educational transformation. The inclusion of AI and IoT in close proximity to education-specific keywords implies an emerging area of research focused on the integration of advanced technologies into teaching, learning, and educational administration.

Cross-Cluster Integration

The overall structure of the network demonstrates a high degree of interconnectivity among clusters. Terms such as "tertiary education," "industry 4.0," and "students" serve as bridging concepts, indicating their cross-cutting relevance across pedagogical, technological, and institutional domains. The network density and the presence of multiple overlapping links suggest a mature and evolving research ecosystem where discussions on education are deeply embedded in the context of technological change.

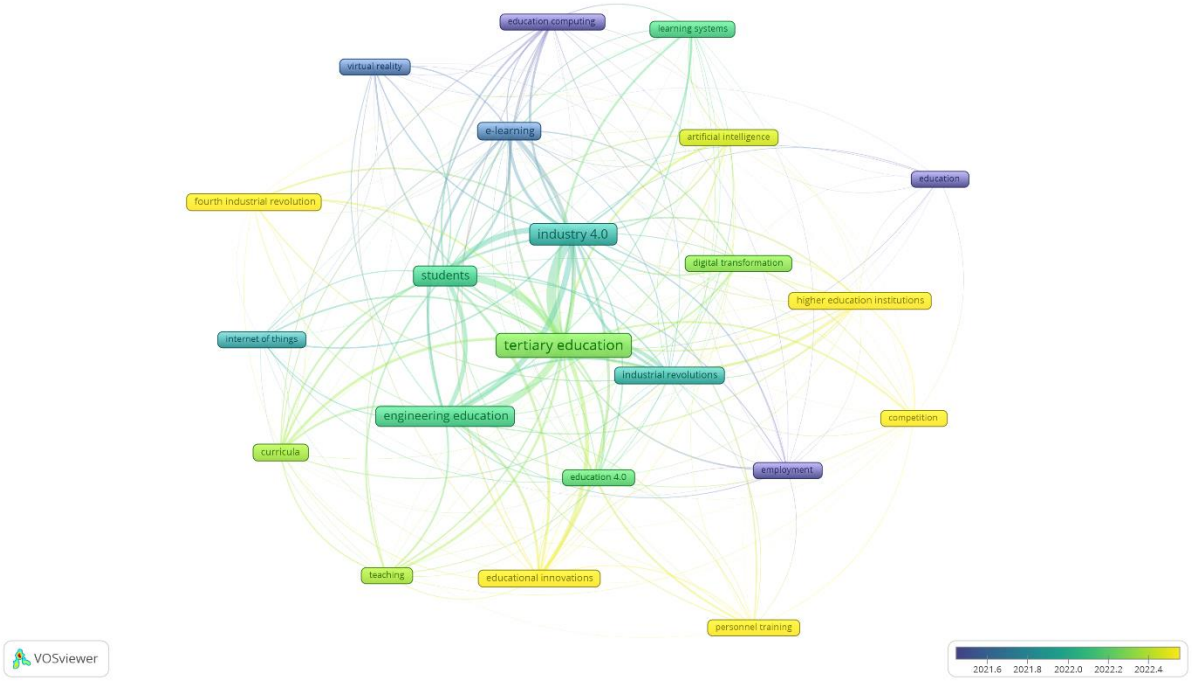

Figure 5. Overlay of Keyword Evolution

Figure 5 illustrates the overlay of keyword co-occurrence, providing insight into how scholarly focus areas have evolved over time within the field of higher education and Industry 4.0. The colours represent the average publication year of documents in which each keyword appears, based on a gradient ranging from dark blue (earliest; 2016) to yellow (most recent, within 2024).

Earlier Research Themes (2016–2019)
Keywords shaded in dark blue to light blue—including "education computing," "e-learning," "virtual reality," and "students"—represent themes that gained attention in the earlier phases of the research period. These topics primarily relate to technology-mediated learning and the initial digitalisation of teaching practices, often discussed in response to early 4IR technologies and pre-pandemic shifts toward digital infrastructure (Okoye et al., 2021).

Midstream Focus Areas (2019–2021)
Keywords in green, such as "tertiary education," "industry 4.0," "engineering education," "teaching," and "curricula," represent the core period of academic activity. These terms indicate a consolidation of discourse around how higher education is responding to 4IR, with research increasingly focusing on curriculum transformation, skill alignment, and pedagogical reforms. The dominance of these themes during the midstream period suggests a strong response from academia during the height of the COVID-19 pandemic and the subsequent rethinking of institutional strategies (Mhlanga and Moloi, 2020).

Emerging Trends (2022–2024)
The keywords appearing in yellow tones—notably "digital transformation," "educational innovations," "employment," "competition," "higher education institutions," "personnel training," and "education 4.0"—represent emerging areas of interest. These topics reflect a forward-looking orientation in current literature, with growing attention to labour market

outcomes, institutional competitiveness, and innovation in educational models. The emergence of terms like "education 4.0" signals an evolution beyond the foundational Industry 4.0 narrative, pointing toward more learner-centred, adaptive, and technology-integrated educational ecosystems (Chakraborty et al., 2023).

Discussion on Future Research Directions: Higher education and Industry 4.0

The findings from the thematic evolution (Figure 3), colour cluster network (Figure 5), and overlay (Figure 5) analyses suggest several promising directions for future research at the intersection of higher education and Industry 4.0. As the field matures, attention is progressively shifting from foundational digitalisation to more complex, systemic, and value-driven transformations in education systems.

From Digital Adoption to Strategic Digital Transformation

While early research emphasised digital learning environments such as e-learning, virtual reality, and education computing, emerging studies are now focused on strategic digital transformation (Bygstad et al., 2022; Hashim et al., 2022). Future research should deepen investigations into how institutions transition from tactical adoption of tools to system-wide integration of technologies aligned with educational missions, institutional governance, and learner outcomes. This includes exploring AI-driven curriculum design**,** learning analytics, and adaptive learning ecosystems that personalise education at scale.

Education 4.0 and Competency-Based Learning

The rise of keywords such as *"education 4.0," "curricula," "teaching,"* and *"educational innovations"* indicates a growing emphasis on reimagining pedagogy in line with the competencies required by the digital economy. Future research should investigate models of competency-based education**,** transdisciplinary learning**,** and problem-based teaching frameworks that prepare learners for complex, automated, and rapidly changing work environments. Longitudinal studies evaluating the effectiveness and scalability of such models across diverse educational settings would be particularly valuable.

Labour Market Alignment and Employment Outcomes

The increased prominence of keywords like "employment," "competition," and "personnel training" suggests a growing concern with the employability of graduates. Future research should explore how educational institutions can better align their curricula with evolving labour market demands, especially in the context of automation and AI-driven job displacement. There is also scope to examine the effectiveness of university-industry partnerships, cooperative education models, and TVET reformation strategies in fostering work-ready graduates (George et al., 2024, Hamid et al., 2024).

Institutional Strategy, Equity, and Policy Innovation

As "higher education institutions" and "digital transformation" emerge as central themes, future studies should address how universities and polytechnics are strategically navigating 4IR transitions, particularly in terms of infrastructure readiness, faculty digital competency, and inclusive access. Comparative studies across regions and institutional types could uncover policy innovations and structural reforms that enhance institutional resilience and inclusivity in the digital era (Mhlanga and Moloi, 2020; Benjamin and Foye, 2022).

Emerging Technologies and Educational Ethics

The emergence of niche, high-density themes such as “artificial intelligence,” “internet of things,” and “learning systems” suggests that future research will likely engage more deeply with technological frontiers. However, this should be accompanied by critical inquiry into the ethical, psychological, and social implications of integrating such technologies into learning (Salah et al., 2023; Bibri, 2022). Issues such as data privacy, algorithmic bias, digital well-being, and the role of human agency in technology-mediated education warrant dedicated investigation.

Conclusion

This study offers a comprehensive bibliometric analysis of the scholarly discourse at the intersection of higher education and Industry 4.0, based on 266 publications indexed in the Scopus database from 2016 to 2025. The analysis reveals a growing body of literature that reflects increasing academic interest in understanding how higher education systems respond to the technological demands of the Fourth Industrial Revolution. The volume of publications has shown a clear upward trend, with the most significant surge occurring between 2020 and 2023, likely driven by the global acceleration of digital transformation in the wake of the COVID-19 pandemic.

Thematic mapping and keyword co-occurrence analyses indicate a shift from early focus areas such as digital learning platforms and e-learning toward more complex and systemic concerns, including strategic institutional transformation, competency-based curriculum reform, labour market alignment, and technological integration. Central research themes include "tertiary education," "industry 4.0," "digital transformation," "education 4.0," and "students," which serve as pivotal nodes connecting pedagogical, institutional, and technological dimensions. The disciplinary composition, primarily rooted in computer science, engineering, and social sciences, further confirms the multidisciplinary nature of this evolving research field.

Despite the breadth and depth of the findings, several limitations should be acknowledged. Firstly, this study is restricted to the Scopus database, which may limit the inclusion of relevant literature available in other databases such as Web of Science, ERIC, or regional repositories. Secondly, the citation impact of recent publications is likely underestimated due to the limited time frame for academic dissemination. Thirdly, keyword-based filtering may have excluded studies using alternative terminology, thereby narrowing the thematic scope. Lastly, bibliometric methods, while valuable for structural and quantitative assessments, do not capture the contextual richness and pedagogical innovation inherent in many of the reviewed studies.

Future research should expand the database coverage and integrate bibliometric methods with qualitative approaches such as content analysis and meta-synthesis to obtain a more nuanced understanding of educational transformation. Longitudinal studies examining the impact of digital integration on institutional performance, graduate employability, and educational access would offer valuable insights. Moreover, the increasing presence of emerging technologies such as artificial intelligence, the Internet of Things, and adaptive learning systems in education warrants deeper exploration into their pedagogical implications, ethical considerations, and governance frameworks. Comparative studies across

different national contexts would also contribute to understanding the varied institutional responses and policy innovations in higher education systems undergoing digital transition.

In conclusion, while the reviewed literature confirms that bibliometric methods are widely used to assess trends in higher education related to digital transformation, pedagogy, and sustainability, there remains a pressing need to bridge these domains with the broader context of Industry 4.0. As higher education continues to evolve within an increasingly technology-driven environment, future scholarship must adopt a more integrative, policy-relevant, and interdisciplinary lens to fully capture the transformative potential of Education 4.0.

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

References

Adel, A. (2024). The convergence of intelligent tutoring, robotics, and IoT in smart education for the transition from industry 4.0 to 5.0. *Smart Cities, 7*(1), 325–369.

Ahmad, E. (2024). The convergence of Education 4.0 and Industry 4.0: A Twin Peaks model. *Journal of Innovative Digital Transformation, 1*(1), 68–83.

Awan, U., Gölgeci, I., Makhmadshoev, D., & Mishra, N. (2022). Industry 4.0 and circular economy in an era of global value chains: What have we learned and what is still to be explored? *Journal of Cleaner Production, 371*, 133621.

Benjamin, O. O., & Foye, V. O. (2022). Inclusion, organizational resilience, and sustainable development in Nigeria: The role of digital innovations. *Environmental Sciences Proceedings, 15*(1), 27.

Bibri, S. E. (2022). The social shaping of the metaverse as an alternative to the imaginaries of data-driven smart cities: A study in science, technology, and society. *Smart Cities, 5*(3), 832–874.

Bonfield, C. A., Salter, M., Longmuir, A., Benson, M., & Adachi, C. (2020). Transformation or evolution?: Education 4.0, teaching and learning in the digital age. *Higher Education Pedagogies, 5*(1), 223–246.

Brika, S., Algamdi, A., Chergui, K., Musa, A., & Zouaghi, R. (2021). Quality of higher education: A bibliometric review study. *Frontiers in Education, 6*, Article 666087.

Broo, D. G., Kaynak, O., & Sait, S. M. (2022). Rethinking engineering education at the age of industry 5.0. *Journal of Industrial Information Integration, 25*, 100311.

Bygstad, B., Øvrelid, E., Ludvigsen, S., & Dæhlen, M. (2022). From dual digitalization to digital learning space: Exploring the digital transformation of higher education. *Computers & Education, 182*, 104463.

Chakraborty, S., Gonzalez-Triana, Y., Mendoza, J., & Galatro, D. (2023). Insights on mapping Industry 4.0 and Education 4.0. In *Frontiers in Education* (Vol. 8, p. 1150190). Frontiers Media SA.

Chamorro-Atalaya, O., Flores-Velásquez, C., Flores-Cáceres, R., Arévalo-Tuesta, J., Zevallos-Castañeda, M., Quispe, G., … & Alarcón-Anco, R. (2024). Use of digital twin technology in the teaching-learning process, in the field of university education: A bibliometric review. *International Journal of Learning, Teaching and Educational Research, 23*(2), 313–329.

Chamorro-Atalaya, O., Olivares-Zegarra, S., Sobrino-Chunga, L., Carranza, V., Vargas-Díaz, A., Huarcaya-Godoy, M., … & Cruz-Telada, Y. (2023). Application of the chatbot in university

education: A bibliometric analysis of indexed scientific production in Scopus, 2013–2023. *International Journal of Learning, Teaching and Educational Research, 22*(7), 281–304.

Dai, Y., Liu, A., & Lim, C. P. (2023). Reconceptualizing ChatGPT and generative AI as a student-driven innovation in higher education. *Procedia CIRP, 119*, 84–90.

Dissanayake, H., Iddagoda, A., & Popescu, C. (2022). Entrepreneurial education at universities: A bibliometric analysis. *Administrative Sciences, 12*(4), 185.

Eberhard, B., Podio, M., Alonso, A. P., Radovica, E., Avotina, L., Peiseniece, L., ... & Solé-Pla, J. (2017). Smart work: The transformation of the labour market due to the fourth industrial revolution (I4.0). *International Journal of Business & Economic Sciences Applied Research, 10*(3).

Fahim, A., Addae, B. A., Ofosu-Adarkwa, J., Qingmei, T., & Bhatti, U. A. (2021). Industry 4.0 and higher education: An evaluation of barriers affecting master's in business administration enrolments using a grey incidence analysis. *IEEE Access, 9*, 76991–77008.

George, W. K., Silas, E. I., Pandey, D., & Pandey, B. K. (2024). Utilization of Industry 4.0 Technologies in Nigerian Technical and Vocational Education: A Conundrum for Educators. In *Examining the Rapid Advance of Digital Technology in Africa* (pp. 270–293). IGI Global.

Guerrero, A., López-Belmonte, J., Marín, J., & Costa, R. (2020). Scientific development of educational artificial intelligence in web of science. *Future Internet, 12*(8), 124.

Haderer, B., & Ciolacu, M. (2022). Education 4.0: Artificial intelligence assisted task-and time planning system. *Procedia Computer Science, 200*, 1328–1337.

Hamid, N., Rasul, M., & Kamaruzaman, F. (2024). Circular economy and sustainable technology in technical and vocational education and training: A bibliometric analysis. *International Journal of Learning, Teaching and Educational Research, 23*(9), 141–160.

Hashim, M. A. M., Tlemsani, I., & Matthews, R. (2022). Higher education strategy in digital transformation. *Education and Information Technologies, 27*(3), 3171–3195.

Hinojo-Lucena, F., Díaz, I., Reche, M., & Rodríguez, J. (2019). Artificial intelligence in higher education: A bibliometric study on its impact in the scientific literature. *Education Sciences, 9*(1), 51.

Huang, C., Yang, C., Wang, S., Wu, W., Su, J., & Liang, C. (2020). Evolution of topics in education research: A systematic review using bibliometric analysis. *Educational Review, 72*(3), 281–297.

Klingenberg, C. O., Borges, M. A. V., & do Vale Antunes Jr, J. A. (2022). Industry 4.0: What makes it a revolution? A historical framework to understand the phenomenon. *Technology in Society, 70*, 102009.

Krishna, V. V. (2024). AI and contemporary challenges: The good, bad and the scary. *Journal of Open Innovation: Technology, Market, and Complexity, 10*(1), 100178.

Kumar, S., Verma, A. K., & Mirza, A. (2024). Digitalisation, Artificial Intelligence, IoT, and Industry 4.0 and Digital Society. In *Digital Transformation, Artificial Intelligence and Society: Opportunities and Challenges* (pp. 35–57). Singapore: Springer Nature Singapore.

León-Gómez, A., Forero, J., & Jaén, J. (2023). A bibliometric analysis of sustainability education in tourism universities. *SAGE Open, 13*(3).

Lillis, T., & Curry, M. J. (2006). Professional academic writing by multilingual scholars: Interactions with literacy brokers in the production of English-medium texts. *Written Communication, 23*(1), 3–35.

Malomane, R., Musonda, I., & Okoro, C. S. (2022). The opportunities and challenges associated with the implementation of fourth industrial revolution technologies to manage health and safety. *International Journal of Environmental Research and Public Health, 19*(2), 846.

Mansor, N. A., Abdullah, N., & Rahman, H. A. (2020). Towards electronic learning features in Education 4.0 environment: Literature study. *Indonesian Journal of Electrical Engineering and Computer Science, 19*(1), 442–450.

Mhlanga, D., & Moloi, T. (2020). COVID-19 and the digital transformation of education: What are we learning on 4IR in South Africa? *Education Sciences, 10*(7), 180.

Mian, S. H., Salah, B., Ameen, W., Moiduddin, K., & Alkhalefah, H. (2020). Adapting universities for sustainability education in Industry 4.0: Channel of challenges and opportunities. *Sustainability, 12*(15), 6100.

Mohamad, A. H. H., Ab-Rahim, R., Kushairi, A. R. E., & Esa, M. S. M. (2024a). Housing market: A bibliometric analysis from 2020 to 2024. *International Journal of Academic Research in Business and Social Sciences, 14*(8), 274–295.

Mohamad, A. H. H., Rosli, S. N. F. A., Ab-Rahim, R., Rashid, N. K. A., & Esa, M. S. M. (2024b). Poverty in Malaysia Region: A bibliometric analysis. *International Journal of Academic Research in Business and Social Sciences, 14*(8), 1676–1700.

Moraes, E. B., Kipper, L. M., Hackenhaar Kellermann, A. C., Austria, L., Leivas, P., Moraes, J. A. R., & Witczak, M. (2023). Integration of Industry 4.0 technologies with Education 4.0: Advantages for improvements in learning. *Interactive Technology and Smart Education, 20*(2), 271–287.

Motyl, B., Baronio, G., Uberti, S., Speranza, D., & Filippi, S. (2017). How will change the future engineers' skills in the Industry 4.0 framework? A questionnaire survey. *Procedia Manufacturing, 11*, 1501–1509.

Mubarak, M. F., & Petraite, M. (2020). Industry 4.0 technologies, digital trust and technological orientation: What matters in open innovation? *Technological Forecasting and Social Change, 161*, 120332.

Omodan, B. I. (2024). Redefining university infrastructure for the 21st century: An interplay between physical assets and digital evolution. *Journal of Infrastructure, Policy and Development, 8*(4), 3468.

Okagbue, E., Ezeachikulo, U., Akintunde, T., Tsakuwa, M., Ilokanulo, S., Obiasoanya, K., … & Ouattara, C. (2023). A comprehensive overview of artificial intelligence and machine learning in education pedagogy: 21 years (2000–2021) of research indexed in the Scopus database. *Social Sciences & Humanities Open, 8*(1), 100655.

Okoye, K., Rodriguez-Tort, J. A., Escamilla, J., & Hosseini, S. (2021). Technology-mediated teaching and learning process: A conceptual study of educators' response amidst the Covid-19 pandemic. *Education and Information Technologies, 26*, 7225–7257.

Okunlaya, R. O., Syed Abdullah, N., & Alias, R. A. (2022). Artificial intelligence (AI) library services innovative conceptual framework for the digital transformation of university education. *Library Hi Tech, 40*(6), 1869–1892.

Pauceanu, A. M., Rabie, N., & Moustafa, A. (2020). Employability under the fourth industrial revolution. *Economics & Sociology, 13*(3), 269–282.

Piątkowski, M. J. (2020). Expectations and challenges in the labour market in the context of industrial revolution 4.0: The agglomeration method-based analysis for Poland and other EU member states. *Sustainability, 12*(13), 5437.

Prieto-Jiménez, E., López-Catalán, L., López-Catalán, B., & Fernández, G. (2021). Sustainable development goals and education: A bibliometric mapping analysis. *Sustainability, 13*(4), 2126.

Raffaghelli, J. E., & Sangrà, A. (2023). Data cultures in higher education: Acknowledging complexity. In *Data cultures in higher education: Emergent practices and the challenge ahead* (pp. 1–39). Cham: Springer International Publishing.

Rof, A., Bikfalvi, A., & Marques, P. (2022). Pandemic-accelerated digital transformation of a born digital higher education institution. *Educational Technology & Society, 25*(1), 124–141.

Salah, M., Al Halbusi, H., & Abdelfattah, F. (2023). May the force of text data analysis be with you: Unleashing the power of generative AI for social psychology research. *Computers in Human Behavior: Artificial Humans, 1*(2), 100006.

Salvador, R., Barros, M. V., Barreto, B., Pontes, J., Yoshino, R. T., Piekarski, C. M., & de Francisco, A. C. (2023). Challenges and opportunities for problem-based learning in higher education: Lessons from a cross-program Industry 4.0 case. *Industry and Higher Education, 37*(1), 3–21.

Sánchez, M., Palos-Sánchez, P., & Folgado-Fernández, J. (2022). Systematic literature review and bibliometric analysis on virtual reality and education. *Education and Information Technologies, 28*(1), 155–192.

Sharma, M., Paliwal, T., & Baniwal, P. (2024). Challenges in digital transformation and automation for Industry 4.0. In *AI-Driven IoT Systems for Industry 4.0* (pp. 143–163). CRC Press.

Sharma, R., Jabbour, C. J. C., & Lopes de Sousa Jabbour, A. B. (2021). Sustainable manufacturing and Industry 4.0: What we know and what we don't. *Journal of Enterprise Information Management, 34*(1), 230–266.

Telukdarie, A., & Munsamy, M. (2019). Digitization of higher education institutions. In *2019 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM)* (pp. 716–721). IEEE.

Tri, N. M., Hoang, P. D., & Dung, N. T. (2021). Impact of the industrial revolution 4.0 on higher education in Vietnam: Challenges and opportunities. *Linguistics and Culture Review*, 1–15.

Van Hoang, T. (2024). Impact of integrated artificial intelligence and internet of things technologies on smart city transformation. *Journal of Technical Education Science, 19*(Special Issue 01), 64–73.

Vanderhorst, H. R., Heesom, D., & Yenneti, K. (2024). Technological advancements and the vision of a meta smart twin city. *Technology in Society, 79*, 102731.

Veile, J. W., Schmidt, M. C., & Voigt, K. I. (2022). Toward a new era of cooperation: How industrial digital platforms transform business models in Industry 4.0. *Journal of Business Research, 143*, 387–405.

Veres, C., Tănase, M., Bacoș, I., & Kardos, M. (2025). Sustainable universities: A bibliometric and thematic analysis in higher education. *Sustainability, 17*(5), 1817.

Vermesan, O., Bröring, A., Tragos, E., Serrano, M., Bacciu, D., Chessa, S., ... & Bahr, R. (2022). Internet of robotic things – Converging sensing/actuating, hyperconnectivity, artificial intelligence and IoT platforms. In *Cognitive Hyperconnected Digital Transformation* (pp. 97–155). River Publishers.

Wawak, S., Teixeira Domingues, J. P., & Sampaio, P. (2024). Quality 4.0 in higher education: Reinventing academic-industry-government collaboration during disruptive times. *The TQM Journal, 36*(6), 1569–1590.

Wei, Y. M., & Lin, H. M. (2024). Scrutinizing business development research: Dynamic retrospective analysis and conceptual evolution. *Administrative Sciences, 14*(4), 81.

Xu, D., Zheng, Y., & Jia, Y. (2021). The bibliometric analysis of the sustainable influence of physical education for university students. *Frontiers in Psychology, 12*, Article 592276.

Yang, J. (2023). The impact of Industry 4.0 on the world of work and the call for educational reform. In *The Frontier of Education Reform and Development in China: Articles from Educational Research* (pp. 285–298). Springer Nature Singapore.