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# Bibliometric Analysis and Visualization of Research on the Integration of Science- Industry-Education

Ting Lan[1,3], Hongwei Sun[2,3]*

[1]School of Economics and Management, Guangzhou College of Applied Science and Technology, Guangzhou, Guangdong, 511370, China

[2]School of Sports Science and Technology, Guangzhou College of Applied Science and Technology, Guangzhou, Guangdong, 511370, China

[3]Urban and Rural Cultural Development Research Center,Guangzhou, Guangdong, 511370, China

**ABSTRACT**

With the accelerated transformation of the global innovation ecosystem, the integration of science-industry-education has become a core mechanism driving technology transfer and industrial upgrading. The deep penetration of digital technology has provided a new path for reconstructing the collaborative model of industry, academia, and research. Based on 1,058 articles from the Web of Science Core Collection, this study employs the CiteSpace tool to conduct bibliometric and knowledge network analysis of research on the integration of science-industry-education from 2000 to 2024. The results indicate that global publication volume has undergone three distinct phases: the embryonic stage (2000–2008), which focused on the construction of the triple helix theory; the growth stage (2009 – 2019), which shifted towards regional institutional validation; and the explosive stage (2020–2024), which deepened digital transformation and efficiency assessment. The core research vehicle is the journal Journal of Technology Transfer, which has formed a disciplinary network where management, computer science, and engineering intersect and permeate each other. Research themes have evolved from early policy framework design to efficiency optimization, with digital transformation and value closure becoming cutting-edge hot topics. However, the cooperation network exhibits characteristics of a 'dual-core drive' dominated by China and the United States, with regional fragmentation coexisting, and the density of inter-institutional cooperation in emerging economies is far lower than that in developed countries. In the future, it is necessary to strengthen interdisciplinary collaboration mechanisms, address the digital divide and institutional compatibility barriers, and promote the deep integration of green technology innovation with an evaluation system oriented toward sustainable development goals. This will provide practical pathways for the high-quality development of a science-industry-education collaborative innovation ecosystem.

**KEYWORDS**

Integration of science- industry- education; University-industry collaboration; Bibliometrics; Visualisation

## 1 Introduction

### 1.1 Research Background

In the knowledge economy era, university-industry-government (Triple Helix) collaborative innovation has become an important engine for promoting technological progress, industrial upgrading, and socially sustainable development [1]. The integration of science-industry-education promotes the transformation of scientific and technological achievements by integrating academic resources, industrial demands, and policy support, and also injects practice-oriented innovative momentum into the higher education system [2]. However, despite the continuous deepening of research and practice in university-industry collaboration (UIC) worldwide [3], issues such as structural unemployment, inadequate quality of applied higher education, and imperfect cooperation mechanisms remain widespread. Therefore, a systematic analysis of the current state of research, cooperation networks, and knowledge evolution trends in global science-industry-education integration is of great theoretical value and practical significance for optimizing innovation ecosystems and enhancing cooperation efficiency.

### 1.2 Literature Review

Motivations and Influencing Factors: The driving factors behind university-industry collaboration and their impact on innovation performance have been a focal point of academic research. Mathisen and Jorgensen (2021)[4] introduced the concept of ‘knowledge readiness,’ emphasizing that the interaction between geographical proximity and cognitive proximity is a key prerequisite for knowledge co-creation. They also highlighted that the complementary knowledge between industry mentors and academic researchers can significantly enhance the innovative value of collaborative projects. Additionally, Togoontumur and Cooray (2024) [5] validated the indirect effects of R&D collaboration on economic growth using cross-country panel data, finding that capital formation is the core mediating variable. However, this effect is not significant in high-income countries, suggesting that collaboration quality must align with regional development

*** Corresponding Author:** Hongwei Sun, 1109856551@qq.com

stages. However, heterogeneous cooperation motives may lead to goal conflicts. For example, enterprises focus more on cost control and human resource acquisition, while universities tend to balance financial support and educational missions [6-7]. The difference in motives may affect the depth of cooperation and even lead to the short-term nature of cooperative projects [8].

The moderating role of geographical and cognitive distance: The interactive effects of geographical distance and cognitive distance are a hot topic in collaborative research. Based on empirical analysis in the Netherlands, Ponds et al. (2010) [9] showed that although geographical proximity promotes knowledge spillovers, cross-regional cooperation networks have a more significant impact on innovation value. This finding challenges the traditional 'local advantage' theory and suggests that the synergy between globalization and localization may become a future trend. Muscio (2013) found that while spatial proximity between Italian universities and businesses can increase cooperation frequency, its impact on cooperation quality (such as patent value) follows an inverted U-shaped curve, with excessive proximity potentially leading to knowledge homogeneity [10].

The impact of policy and institutional environments: The role of government funding and regulatory reforms in shaping the collaborative ecosystem has garnered significant attention. Nugent et al. (2022) compared two types of research and development funding programs in Australia and found that projects specifically targeting industry-academia collaboration could temporarily increase patent numbers but had limited long-term effects, suggesting that policy design should balance market orientation and basic research [11]. The relaxation of university regulations in Japan in 1998 shifted the leadership of industry-academia collaboration from 'industry-academia cooperation' to 'industry-academia synergy,' expanding the scope of collaboration but weakening industry-government interaction, reflecting the restructuring effects of institutional changes on the triple helix relationship [12].In addition, human resource management strategies (such as salary incentives and the stability of university-industry liaison offices) have been proven to be key variables in the performance differences of Korean universities' collaborations [13].

Assessment of collaborative performance and contradictions: The measurement standards for collaborative performance and their inherent contradictions are currently the focus of controversy. Wang et al. (2015) used panel data from Chinese universities to find that the breadth of collaboration is linearly positively correlated with academic performance, while the depth of collaboration shows an inverted U-shaped curve, suggesting that over-reliance on a single channel may inhibit original output [14]. Similarly, Zhang and Wang (2017) pointed out the negative impact of the intensity of industry-academia collaboration on scholars' h-index, but social capital (such as relationship strength) can effectively mitigate this contradiction [15]. These findings challenge the simplistic logic that 'more cooperation is always better' and emphasize the need to reconfigure evaluation systems from a quality perspective [16]. Additionally, studies on patent commercialization indicate that while joint patent applications between universities and enterprises can enhance short-term market value, independently held patents by universities have higher long-term technological influence, suggesting that cooperation models should be aligned with commercialization stages [17].

The review of existing literature provides valuable insights into the driving forces and implementation pathways of industry-academia-research integration. However, most studies focus on single countries or industry cases and lack cross-regional and cross-disciplinary integration analysis. Existing findings are mostly based on cross-sectional data or short-term tracking and fail to reveal the long-term evolutionary patterns of cooperation networks and knowledge flows [18]. Existing theories are mostly based on experiences in Europe and the United States, with insufficient attention to the unique institutional barriers (e.g., intellectual property fragmentation, and conflicts between university and enterprise cultures) in emerging economies such as China and India [19-20].

### 1.3 Research Objectives and Significance

This study uses the CiteSpace bibliometric method to conduct a systematic analysis of the integration of science-industry-education, aiming to answer the following key questions:

a. What are the temporal evolution characteristics of the number of publications on the integration of science-industry-education? In which core journals are the main research results in this field published?

b. What kind of cooperation network has been formed among individual researchers, research institutions, and countries/regions? Are there core groups of authors and key research institutions? What role does international cooperation play in knowledge production?

c. How is science-industry-education integration distributed across disciplines? What are the characteristics of interdisciplinary cooperation in this field?

d. What are the patterns of replacement of research hotspots in different periods? What are the emerging themes currently at the forefront of research?

Through multi-dimensional bibliometric analysis, this study systematically maps the knowledge landscape of the integration of science-industry-education, revealing the development patterns and evolutionary trends of this field. It provides theoretical foundations and practical guidance for constructing a more efficient industry-academia-research collaborative innovation ecosystem. The research findings not only address the shortcomings of traditional literature reviews in terms of objectivity and systematicness but also provide a verifiable knowledge framework for future research.

## 2 Data and Methods

### 2.1 Research Methodology

In recent years, bibliometrics has become an important method for analyzing literature reviews and is widely used in disciplinary fields. It can analyze a huge amount of literature data, visualize the network relationship and evolution process among knowledge units, and reveal the potential knowledge structure and information. This method provides new perspectives and a quantitative basis for researching the current situation and trends in the field and enhances the objectivity and scientificity of research conclusions. VOSviewer and CiteSpace are commonly used bibliometric tools in academia. VOSviewer is suitable for quickly visualizing collaborative networks and co-occurring relationships, while CiteSpace is more powerful in analyzing dynamic evolution and emergent trends, and is suitable for in-depth exploration of the development of the field. CiteSpace is more powerful in analyzing dynamic evolution and emergent trends, and is suitable for in-depth excavation of the development of the field. Therefore, this study utilizes CiteSpace (6.2. R3) in conjunction with in-depth literature analysis to comprehensively examine and interpret the research theme of science-industry-education integration through the integrated application of quantitative and qualitative methods.

### 2.2 Data Sources

As an authoritative database widely recognized by academics, the literature included in Web of Science undergoes a rigorous peer-review and editorial review process, and the literature data in WoS can achieve the most complete collaborative network, co-occurrence analysis, and co-citation analysis. This study relies on the Web of Science core collection as the data source, specifically covering the two core citation indexes, Science Citation Index Expanded (SCIE) and Social Science Citation Index (SSCI). In order to focus on the research theme of integration of science-industry-education, this study adopts a thematic search strategy, which is expressed as follows: ((TS= (Integration of Science-Industry-Education)) OR TS=(University-industry collaboration)) OR TS=(Science and technology park* AND Production-education integration)). The literature search was completed on 20 February 2025, and the time frame of the search was set from 2000 to 2024, initially obtaining 1,153 documents; restricting the language of the literature to English, removing 9 documents, leaving 1,144 documents; restricting the type of the literature to "Article" and browsing the abstracts one by one, and removing duplicates, removing 1,144 documents; restricting the type of the literature to "Article", browsing the abstracts one by one, and removing duplicates. By limiting the type of document to "Article" and browsing the abstracts one by one and removing duplicates, 86 documents were removed, leaving 1,058 documents.

## 3 Results

### 3.1 Statistical Analysis of Communications

Figure 1 shows that the change in the number of articles published by scholars in the field of science-industry-education integration shows an overall increasing trend ($R^2 > 0.88$). According to the trend of the number of publications of research related to science-industry-education fusion from 2000 to 2024, it can be divided into three phases: the budding period (2000-2008) with less than 10 publications per year on average and significant fluctuations, reflecting the unstable nature of the field's early explorations; the growth period (2009-2019) with steady growth to an average of 43 publications per year, which focuses on the drivers of collaborative research and development between universities and companies, Technology linkage between academia and industry; The explosive period (2020-2024) has accelerated the growth rate, with an annual average of 95 articles, reaching a peak of 111 articles in 2023, showing that interdisciplinary fusion is driven by technological breakthroughs and that the integration of industry and education promotes the innovation of sustainable business models.

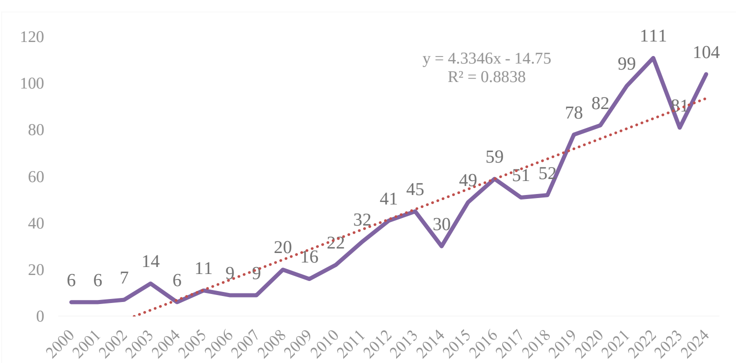


Figure 1 Trends in statistics on the number of articles issued

From the searched literature, a total of 1,058 research papers related to science-industry-education integration have been published in 200 academic journals during the last twenty-five years. The top ten journals in terms of extracted publications are shown in Table 1, JOURNAL OF TECHNOLOGY TRANSFER (8.3%), SCIENTOMETRICS (5.6%), RESEARCH POLICY (4.5%), TECHNOLOGICAL FORECASTING AND SOCIAL CHANGE (4.1%), and SUSTAINABILITY (4.0%) journals have a particularly strong share of output. These findings provide an important reference basis for researchers to accurately locate the core journals in this field.

Table 1 Main journals in which articles are published

| Rank | Publication Titles | IF | Count | percentage |
|---|---|---|---|---|
| 1 | JOURNAL OF TECHNOLOGY TRANSFER | 4 | 88 | 8.3% |
| 2 | SCIENTOMETRICS | 3.5 | 59 | 5.6% |
| 3 | RESEARCH POLICY | 7.5 | 48 | 4.5% |
| 4 | TECHNOLOGICAL FORECASTING AND SOCIAL CHANGE | 12.9 | 43 | 4.1% |
| 5 | SUSTAINABILITY | 3.3 | 42 | 4.0% |
| 6 | TECHNOVATION | 11.1 | 33 | 3.1% |
| 7 | TECHNOLOGY ANALYSIS STRATEGIC MANAGEMENT | 2.9 | 29 | 2.7% |
| 8 | SCIENCE AND PUBLIC POLICY | 2.6 | 27 | 2.6% |
| 9 | JOURNAL OF THE KNOWLEDGE ECONOMY | 4 | 20 | 1.9% |
| 10 | INDUSTRY AND INNOVATION | 3.4 | 19 | 1.8% |

Figure 2 shows the high-output authors in the field of industry-academia-research integration and their collaboration networks, with 591 nodes, 422 connections, and a network density of 0.0024, indicating that there are few collaborative relationships among authors and that a group of high-output authors has not yet formed. There are two groups of researchers in this field with the most frequent and robust collaborations: one group consists of Frenken, Koen, and Salimi, Negin; the other group consists of Abramo, Giovanni, and D'angelo, Ciriaco Andrea.

As shown in Table 2, among researchers engaged in industry-academia-research integration, Abramo, Giovanni, Azagra-caro, Joaquin M, and Frenken, Koen have the highest number of publications, with each researcher publishing approximately 7 papers over the past 25 years. Among them, Frenken, and Koen began researching this topic as early as 2007 and have collaborated with a large number of co-authors.

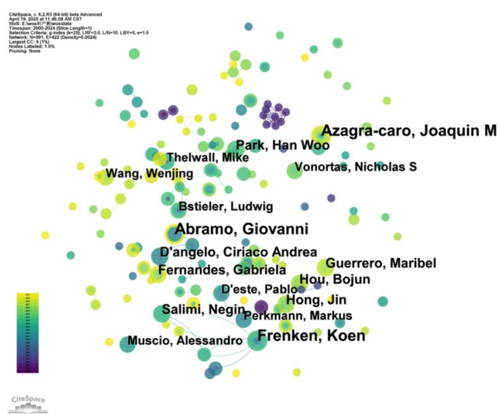


Figure 2 Author Collaboration Network

Table 2 Statistics on authors of publications

| Rank | Count | Centrality | Year | Author |
|---|---|---|---|---|
| 1 | 7 | 0 | 2009 | Abramo, Giovanni |
| 2 | 7 | 0 | 2013 | Azagra-caro, Joaquin M |
| 3 | 7 | 0 | 2007 | Frenken, Koen |
| 4 | 5 | 0 | 2009 | D'angelo, Ciriaco Andrea |
| 5 | 5 | 0 | 2020 | Fernandes, Gabriela |
| 6 | 5 | 0 | 2021 | Guerrero, Maribel |
| 7 | 5 | 0 | 2019 | Hong, Jin |
| 8 | 5 | 0 | 2019 | Hou, Bojun |
| 9 | 5 | 0 | 2015 | Park, Han Woo |
| 10 | 5 | 0 | 2015 | Salimi, Negin |

## 3.3 Institutional Co-operation Networks

The visualization of institutional collaboration is illustrated using the "Institution" module in CiteSpace for the issuing institutions of the literature. The threshold value of Figure 3 is set to 20, with 390 nodes, 316 connecting lines, and a density of 0.0042, the larger the node, the more the institution has published; the centrality reflects the importance of the node, and the institutions with purple outer circles show their important contributions in the field of science - industry-education integration.

Table 3 shows the global inter-institutional collaboration status for research, industry, and education integration. Among the top 10 institutions, eight are located in European countries such as the United Kingdom, Spain, and Sweden (University of London, Consejo Superior de Investigaciones Científicas (CSIC), CSIC-UPV - Instituto de Gestión de la Innovación y del Conocimiento (INGENIO), Universitat Politècnica de Valencia, Newcastle University - UK, Imperial College London, Lund University, and KU Leuven), while the remaining two are from China (Chinese Academy of Sciences) and the United States (University of California System). This indicates that industry-academia-research collaboration is a highly prioritized topic for institutions in these regions. Additionally, the University of London and CSIC have contributed a significant number of publications. Newcastle University - UK has the highest centrality (0.16), indicating the strongest collaboration or connections between the observed nodes and other nodes.

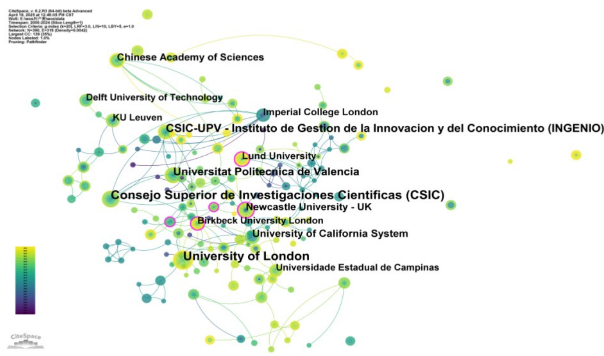


Figure 3 Map of collaborating institutions

Table 3 Statistics on institutional collaboration

| Rank | Count | Centrality | Year | Institution |
|---|---|---|---|---|
| 1 | 24 | 0.02 | 2006 | University of London |
| 2 | 23 | 0.04 | 2008 | CSIC |
| 3 | 17 | 0.01 | 2008 | INGENIO |
| 4 | 16 | 0.06 | 2009 | Universitat Politecnica de Valencia |
| 5 | 13 | 0.06 | 2005 | University of California System |
| 6 | 11 | 0.16 | 2008 | Newcastle University - UK |
| 7 | 11 | 0.02 | 2013 | Chinese Academy of Sciences |
| 8 | 10 | 0.05 | 2001 | Imperial College London |
| 9 | 10 | 0.11 | 2012 | Lund University |
| 10 | 9 | 0.01 | 2003 | KU Leuven |

### 3.4 National or Regional Cooperation Networks

Figure 4 visually presents the pattern of scientific research cooperation among countries through node sizes and connection relationships, with a total of 84 nodes and 54 connections. The United States, China, and England, as the largest nodes, occupy core positions, forming a stable triangular cooperation structure, indicating that these countries have dominant influence in scientific research cooperation. Medium-sized nodes such as Germany and Australia show their participation as secondary hubs, while small nodes such as Finland and Portugal are located at the periphery of the network with relatively limited cooperation. Overall, the network exhibits a distinct ‘core-periphery’ structure, with core countries maintaining network stability through frequent cooperation, while peripheral countries rely on core nodes to access research resources.

Table 4 reveals the characteristics of national cooperation from a quantitative perspective. China ranks first with 190 publications, but its centrality is 0, suggesting that its cooperation model is primarily volume-driven rather than multi-lateral hub-type collaboration. In contrast, the United States (158 publications) and England (155 publications) combine high-frequency cooperation with significant centrality (0.24/0.12), indicating that they are capable of both broad participation and network regulation. The Netherlands (0.38) and Sweden (0.23) stand out with exceptionally high centrality, highlighting their strategic value as ‘research intermediaries,’ despite ranking only 8th and 9th in terms of cooperation frequency. In terms of time, the early activity of the United States (2000) and Germany (2003) contrasts sharply with the later rise of China (2008) and Spain (2008), reflecting the generational transition of global research leadership. Notably, the structural weaknesses of Asian countries such as China and Republic of Korea (0 centrality) may be related to their internationalization strategies in research or data coverage biases. These quantitative indicators provide empirical support for the network structure observed in the figure.

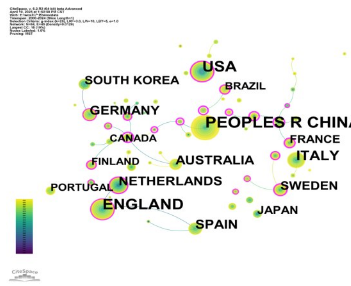


Figure 4 International Cooperation Map

Table 4 Statistics on National Cooperation

| Rank | Count | Centrality | Year | Country |
|---|---|---|---|---|
| 1 | 190 | 0 | 2008 | PEOPLES R CHINA |
| 2 | 158 | 0.24 | 2000 | USA |
| 3 | 155 | 0.12 | 2001 | ENGLAND |
| 4 | 94 | 0.08 | 2006 | ITALY |
| 5 | 69 | 0.04 | 2008 | SPAIN |
| 6 | 65 | 0.08 | 2002 | AUSTRALIA |
| 7 | 65 | 0.12 | 2003 | GERMANY |
| 8 | 63 | 0.38 | 2003 | NETHERLANDS |
| 9 | 50 | 0.23 | 2006 | SWEDEN |
| 10 | 49 | 0 | 2001 | REPUBLIC OF KOREA |

### 3.5 Subject Area Analysis

Figure 5 reveals the typical structural characteristics of global science-industry-education integration across disciplines through the interconnections between disciplinary nodes: 1) With MANAGEMENT and BUSINESS as core nodes, a dual-core driving model of institutional innovation and business practice is formed, and its strong connections with ENGINEERING and INDUSTRIAL reflect the demand for engineering education transformation; 2) COMPUTER SCIENCE, INTERDISCIPLINARY APPLICATIONS (centrality 0.49) serve as a key hub connecting traditional fields such as OPERATIONS RESEARCH with emerging directions like GREEN & SUSTAINABLE SCIENCE, highlighting the enabling role of digital technology in industry-education integration; 3) ENVIRONMENTAL STUDIES and other sustainability-focused disciplines form an independent subnetwork but with weak connections, suggesting that the cultivation of green skills remains in its early stages. The overall structure of the map presents a three-tiered integrated architecture of ‘management-technology-ecology,’ which is highly consistent with international practices such as Germany's Industry 4.0 education and MIT's new engineering education transformation. Table 5 visually illustrates the disciplinary landscape of global science-industry-education integration research: MANAGEMENT (444 mentions), BUSINESS (174 mentions), and ENGINEERING, INDUSTRIAL (154 mentions) constitute the three core disciplinary fields, with MANAGEMENT holding an absolutely dominant position; despite only 74 collaboration instances, it has the highest centrality of 0.49, making it a key hub discipline; the temporal dimension shows a clear generational evolution, with traditional disciplines such as MANAGEMENT remaining active since 2000 while emerging fields such as GREEN & SUSTAINABLE SCIENCE only began to emerge in 2011. This distribution pattern aligns closely with the development trajectory of industry-education integration under the current global industrial transformation and upgrading context, particularly highlighting the unique value of digital technology disciplines in bridging traditional and emerging fields. Highly cited literature in the MANAGEMENT discipline reveals the reasons and types of collaboration between universities and enterprises, explores the factors hindering collaboration and how to reduce these obstacles, and evaluates the outcomes of industry-academia integration and its impact on the innovation and entrepreneurship ecosystem.

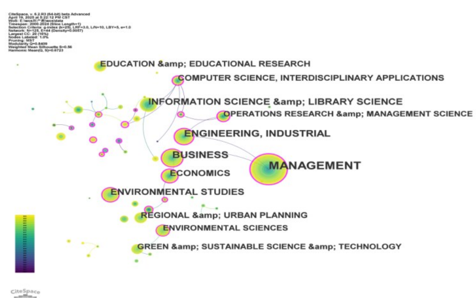


Figure 5 Co-occurrence network of subject areas

Table 5 Statistics of subject areas

| Count | Centrality | Year | WoS Category |
|---|---|---|---|
| 444 | 0.46 | 2000 | MANAGEMENT |
| 174 | 0.4 | 2002 | BUSINESS |
| 154 | 0.44 | 2000 | ENGINEERING, INDUSTRIAL |
| 118 | 0.02 | 2003 | INFORMATION SCIENCE & LIBRARY SCIENCE |
| 109 | 0.25 | 2002 | ENVIRONMENTAL STUDIES |
| 101 | 0.41 | 2003 | ECONOMICS |
| 79 | 0 | 2002 | REGIONAL & URBAN PLANNING |
| 75 | 0 | 2002 | EDUCATION & EDUCATIONAL RESEARCH |
| 74 | 0.49 | 2001 | COMPUTER SCIENCE, INTERDISCIPLINARY APPLICATIONS |
| 61 | 0.44 | 2000 | OPERATIONS RESEARCH & MANAGEMENT SCIENCE |
| 57 | 0.18 | 2016 | ENVIRONMENTAL SCIENCES |
| 55 | 0.04 | 2011 | GREEN & SUSTAINABLE SCIENCE & TECHNOLOGY |
| 48 | 0.04 | 2001 | ENGINEERING, MULTIDISCIPLINARY |
| 47 | 0 | 2003 | MULTIDISCIPLINARY SCIENCES |

### 3.6 Research Hotspot Analysis

Figure 6 shows the keywords in the field of industry-academia-research integration.The size of the nodes and the size of the words reflect the frequency of the keywords, while the lines indicate the co-occurrence relationships between keywords. The two largest keywords in this diagram are 'innovation' and 'university-industry collaboration,' indicating that current research focuses on university-driven industry-academia collaboration innovation ecosystems. Core keywords such as 'University,' 'Entrepreneurship,' and 'Triple Helix' reveal that the main research thread centers on the pivotal role of universities in the knowledge economy. Keywords with a centrality greater than 1 are considered to have significant influence within the research field. As shown in Table 6, the keyword with a centrality greater than 0.1 is 'collaboration.' From a temporal perspective, the early phase (2001 – 2003) focused on foundational keywords such as 'science' and 'innovation,' the middle phase (2004–2005) delved into mechanisms such as 'knowledge transfer' and 'university-industry collaboration,' and the later phase (2007) shifted toward application and evaluation dimensions such as 'performance' and 'research and development,' reflecting the evolution of research from theoretical construction to practical efficacy analysis.


Figure 6 Keyword co-occurrence network

Table 6 Statistics of high-frequency keywords

| Count | Centrality | Year | keywords |
|---|---|---|---|
| 293 | 0.05 | 2003 | innovation |
| 235 | 0.02 | 2005 | university-industry collaboration |
| 193 | 0.06 | 2007 | performance |
| 173 | 0.02 | 2007 | knowledge |
| 171 | 0.03 | 2004 | knowledge transfer |
| 165 | 0.06 | 2001 | science |
| 153 | 0.02 | 2007 | research and development |
| 148 | 0.02 | 2005 | technology transfer |
| 140 | 0.04 | 2004 | impact |
| 132 | 0.19 | 2002 | collaboration |

Figure 7 shows the co-occurring keywords grouped into seven thematic clusters, with each cluster representing a sub-field of research. Cluster 0 is related to 'triple helix,' with 170 clusters and a silhouette value of 0.899; Cluster 1 is related to 'university-industry collaboration,' with 144 clusters and an average silhouette value of 0.802; Cluster 2 is related to 'innovation performance,' with 142 members and an average silhouette value of 0.896; Cluster 3 is related to 'academic entrepreneurship,' with 124 members and an average silhouette value of 0.878; Cluster 4 is related to 'research and development,' with 37 members and an average silhouette value of 0.902; Cluster 5 is related to 'scientific collaboration,' with 29 clusters and an average contour value of 0.995; Cluster 6 is related to 'technology transfer,' with 22 clusters and an average contour value of 0.976.

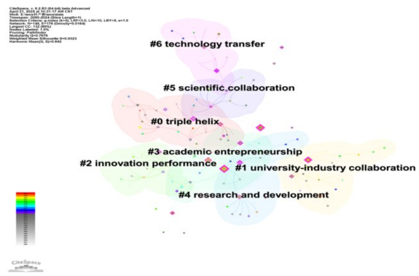


Figure 7 Keyword Clustering Map

### 3.7 Analysis of Evolutionary Trends

Figure 8 shows the changes in the seven clustered themes over time. It can be seen that the evolution of research on the integration of science-industry-education exhibits distinct phased characteristics and a trend toward thematic deepening. Research in this field can be divided into three main stages: 1) Theoretical framework construction phase (2000 – 2008). Centred on the Triple Helix theory, this phase focused on the construction of the university-industry-government relationship model. Etzkowitz and Leydesdorff (2000) proposed the Triple Helix innovation theory, laying the theoretical foundation. This phase emphasized institutional coordination mechanisms and established a framework for analyzing innovation systems. 2) Regional Practice Exploration Phase (2009–2019). Research shifted to empirical studies of regional innovation systems, revealing distinct geographical differences. Ponds et al. (2010) validated the inter-organizational knowledge spillover effect using a knowledge production function. Wei et al. (2013) analyzed Chinese patent data and concluded that geographical distance is a significant barrier to industry-academia collaboration. Fischer et al. (2019) analyzed the patent networks of Brazilian universities, identifying unique institutional evolution pathways in emerging economies. 3) Efficiency Optimisation Deepening Phase (2020 to present). Research has focused on evaluating the effectiveness of cooperation and knowledge conversion mechanisms. Salimi (2023) developed the BWM-DEA model to quantify the efficiency of PhD training. Martínez-Ardila (2023) validated the association between the frequency of university-industry collaboration and the creation of spin-off firms through patent network analysis.

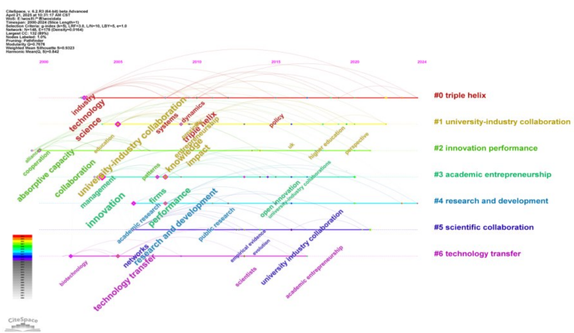


Figure 8 Timeline of keyword clustering

Keyword outbursts are indicators of hot and emerging trends within a research field, signaling a major academic focus. Figure 9 shows the top 25 keywords with the highest citation outbursts from 2020 to 2024. According to the keyword outburst intensity mapping, the hotspots of research on the integration of science-industry-education between 2000 and 2024 show a clear stage-by-stage evolutionary feature. In the early stage (2000-2010), basic theory research is dominated by "science" (intensity 7.38, 2003-2010) and "biotechnology" (intensity 5.97, 2002-2016), reflecting the exploration of the nature of commercialization of science in this stage. In the mid-term (2011-2018), there is a shift towards the study of practical mechanisms, with the explosion of 'patterns' (intensity 7.86, 2007-2015) and 'public research' (intensity 4.88, 2011-2019) highlighting the diversified explorations of collaboration models. In the near future (2019-2024), the focus is on performance evaluation and innovation ecology, with short-term high-intensity outbreaks of "open innovation" (intensity 6.81, 2020-2022) and "innovation performance" (intensity 4.11, 2021-2022), signaling a deepening of the research towards the validation of applied value. Notably, "academic research" (intensity 9.16, 2006-2017), the keyword with the strongest outbreak, has an active period of 12 years, confirming the continuous status of basic research in the integration of science-industry-education. The recent outbreaks of "academic entrepreneurship" (intensity 4.67, 2021-2024) and "university-industry collaboration" (intensity 4.27, 2021-2022) signify that academic entrepreneurship and collaborative mechanisms will become an important direction for future research.

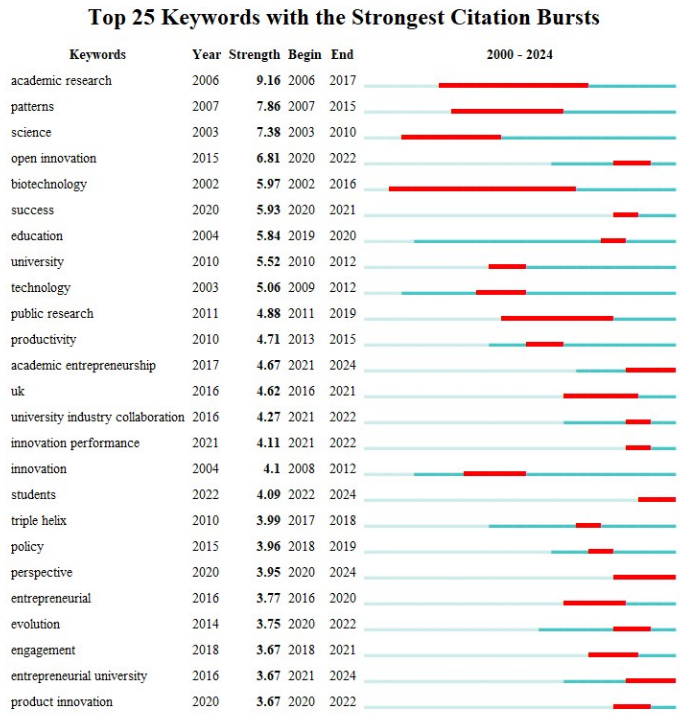


Figure 9 Keyword burst emergence graph

# 4 Discussion

## 4.1 The Evolution of Research on Science-Industry-Education Integration and Its Core Carriers

### 4.1.1 Evolution of Research Stages

According to bibliometric data, global research on science-industry-education integration underwent three stages of transition between 2000 and 2024: The embryonic stage (2000–2008) was mainly characterized by the construction of institutional theories. The average annual number of publications was only 8.2, with core literature such as the triple helix model proposed by Etzkowitz and Leydesdorff, which laid the theoretical foundation for university-industry-government collaborative innovation. Empirical studies by Mowery and Sampat on the technology transfer mechanisms of U. S. universities indicated that the number of university patent authorizations increased significantly after the implementation of the Bayh-Dole Act. Growth phase (2009–2019): Shifted to regional practice verification. The average annual number of publications jumped to 42.5, representing a growth rate of 418%, with the first publication peak occurring in 2013 (45 articles). Typical cases include the institutional evolution of Brazil's university patent network and the localization of China's industry-academia collaboration.

The explosive phase (2020–2024) focused on efficiency assessment and digital transformation. Evers and Ostergaard used a genetic matching algorithm to confirm that industry-academia collaboration increased the proportion of PhD employees in Danish companies by 23%, marking an upgrade in research methods toward causal inference. Sati used the Entropy Weight-TOPSIS method to study the EU and candidate countries and found that countries with low industry-academia collaboration scores also had relatively low digital innovation performance among SMEs. Shi used panel data from 443 innovative firms to demonstrate the impact of industry-academia collaboration on firm innovation efficiency.

### 4.1.2 Distribution Characteristics of Core Journals

Literature metrics analysis indicates that core journals in the field of science-industry-education integration research encompass three major categories: 1) Technology transfer-oriented journals dominate knowledge production. The Journal of Technology Transfer (IF=4) leads with 8.3% of publications (88 articles); Technovation (IF=11.1) exhibits a ‘quality-quantity paradox’: despite accounting for only 3.1% of publications, its high impact factor reflects methodological innovation. 2) Policy journals highlight the theory-practice gap. Research Policy (IF=7.5) leads policy research with 4.5% of publications (48 articles), while Science and Public Policy (IF=2.6) often combines theory with empirical evidence. 3) Emerging interdisciplinary journals (Sustainability and Technological Forecasting and Social Change) reflect paradigm shifts, with two major trends—sustainability integration and AI-driven methodologies—redefining disciplinary boundaries.

## 4.2 Structural Heterogeneity of Cooperation Networks and Knowledge Production Mechanisms

At the national level: China and the United States have formed a ‘dual-core’ pattern, with China ranking first globally in terms of the number of publications (190) but with a centrality of 0, reflecting a ‘high-output but isolated’ characteristic; the Netherlands (centrality 0.38) and Sweden (0.23) have become ‘hidden hubs’ for cross-regional cooperation through their intermediary roles. This finding complements Okamuro et al.'s conclusions on Japanese industrial clusters: geographical proximity is not a necessary condition for successful cooperation, but cognitive proximity must be actively constructed through policy tools. At the institutional level: European universities such as Newcastle University (centrality 0.16) and the Polytechnic University of Valencia (0.06) occupy structural hole positions through interdisciplinary networks, confirming Tolin and Piccaluga's observation that university-led alliance networks (such as Italy's UniSMART community) can reduce technology transfer cycles by 40%. Author collaboration: With a network density of only 0.0024, this indicates that a stable academic community has not yet formed within the field. This supports Mathisen and Jorgensen's ‘knowledge readiness’ theory: temporary geographical proximity (such as corporate mentors stationed on campus) can increase collaboration frequency, but sustained innovation relies on cognitive synergy.

### 4.3 Disciplinary Fields Exhibit Concentration and Interdisciplinary Characteristics

From the distribution of literature by discipline, the field is concentrated in three major areas: management (444 times), business (174 times), and industrial engineering (154 times), forming a dual-core drive of institutional innovation and practical application. Computer science (centrality 0.49) serves as a key hub discipline, connecting traditional fields (such as operations research) with emerging directions (green technology), and highlighting the enabling role of digital technology in the transformation of engineering education. Interdisciplinary collaboration exhibits three main characteristics: 1) Management-technology synergy innovation, For example, MIT's new engineering education program integrates Industry 4.0 and 5.0 technologies into the smart factory learning environment at the Monterey Institute of Technology and Education to address challenges from smart manufacturing; 2) Sustainable development disciplines have formed an independent sub-network, but survey and interview data indicate that green skills development remains in its early stages; 3) Emerging fields such as environmental science are rapidly emerging, reflecting the surging demand for eco-friendly talent driven by industrial transformation.

### 4.4 Knowledge Maps and Cutting-edge Developments in Research Hotspots

The evolution of research hotspots in science-industry-education integration follows a three-stage pattern: the theoretical framework stage (2000 – 2008) centred on the triple helix model and focused on the construction of institutional coordination mechanisms. The regional practice phase (2009 – 2019) shifted to empirical studies of cooperative models, with keywords such as ‘technology transfer’ (148 occurrences) emerging, revealing the institutional evolution pathways of emerging economies. The efficiency enhancement phase (2020 – 2024) focuses on digital transformation and value closure.

From the keyword emergence analysis in the preceding text, it can be concluded that academic entrepreneurship and collaborative mechanisms will become important research directions in the future. Future research should focus on three aspects: dynamic matching mechanisms enabled by digital technology, such as the application of blockchain smart contracts in intellectual property rights confirmation; policy adaptation in complex institutional environments, such as the inverted U-shaped threshold effect of China's regional policy complexity and innovation output; and the path of capability reconstruction for academic entrepreneurs, which requires resolving the dual paradox of ‘research inertia’ and ‘market sensitivity.’ Innovation in research methods is equally critical, requiring the development of hybrid models that integrate patent citation networks with entrepreneurial performance evaluation to provide theoretical foundations and practical tools for building an open, sustainable science-industry-education collaboration ecosystem.

## 5 Conclusions

### 5.1 Policy Implications

Differentiated institutional design: High-income countries should strengthen long-term cooperation oriented towards basic research while emerging economies should focus on application and conversion.

Reconstruction of core capabilities: Universities should establish ‘innovation brokers’ positions, and enterprises should establish a ‘dual channel mechanism’ for knowledge absorption. The case of Ethiopia shows that local knowledge management has significantly improved the efficiency of industry-academia matching.

Three-dimensional evaluation system: A ‘academic-economic-social’ value indicator system should be established, incorporating patent economic lifespan[56]and contributions to the Sustainable Development Goals (SDGs) (e.g., carbon emissions reduction) into performance evaluations.

### 5.2 Research Limitations

The WoS database focuses on English-language literature, resulting in insufficient coverage of local practices in Latin America and Africa, with potential data biases; the use of a single bibliometric method limits the analysis of unstructured data from in-depth interviews.

### 5.3 Future Outlook

In the future, research on the integration of science-industry-education should focus on three key areas: first, deepening cross-disciplinary collaboration mechanisms to promote the integration of cutting-edge fields such as biomedicine and artificial intelligence with industrial practice, and utilizing intelligent algorithms to optimize the matching of industry-academia-research resources; second, strengthening data-driven dynamic simulation capabilities to develop prediction models based on real-world scenarios, providing dynamic simulation tools for policy-making; and third, focusing on the unique paths of emerging economies to address the mechanisms by which institutional differences affect the effectiveness of cooperation. Additionally, a three-dimensional evaluation system encompassing economic, social, and ecological dimensions should be established, incorporating sustainability indicators such as carbon emission intensity into the assessment of cooperation outcomes. Research methodologies should integrate big data mining with in-depth case analysis to uncover the patterns of implicit knowledge flow between academia and industry, thereby driving a spiral-shaped upgrade of theoretical construction and practical validation.

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