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Integrating Blended Learning in Engineering Education: A Bibliometric Study of Research Trends and Impact

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Abstract

Blended learning has become a prominent approach in engineering education, integrating face-to-face and online modalities. Despite its increasing adoption, research on this topic remains underexplored in a systematic manner. The study applies a bibliometric mapping analysis to examine the evolution of blended learning research in engineering education from 2014 to 2024. A total of 180 peer-reviewed journal articles were retrieved in June 2025 from Scopus and ERIC, and analyzed using VOSviewer and Microsoft Excel. The study identifies publication trends, influential authors, journals, institutions, and countries, and visualizes co-authorship and keyword co-occurrence networks. Findings reveal a post-2020 surge in publications, with significant contributions from North America and Europe, particularly Purdue University. Keyword clustering analysis highlights five thematic directions: course design, learning environments, institutional frameworks, student outcomes, and motivation. Despite these advancements, gaps remain in systemic implementation, longitudinal evaluation of graduate competencies, and cross-regional collaboration. This study offers a comprehensive, data-driven synthesis that not only consolidates the existing literature but also provides actionable insights for researchers, educators, and policymakers. By linking bibliometric evidence to established learning theories, the findings inform both academic research and institutional strategies, and set clear priorities for advancing blended learning as a sustainable and impactful component of engineering education worldwide.

Keywords: Blended learning, engineering education, keyword co-occurrence, scientific mapping, VOSviewer.

1. Introduction

In the context of rapid innovation and digital transformation in higher education, blended learning has emerged as a strategic approach to enhance teaching and learning effectiveness, particularly in engineering education. The flexible integration of online and face-to-face activities enables learners to manage their own pace, schedule, and learning environment, while fostering higher-order skills such as problem-solving and collaboration [1].

Engineering education, with its strong emphasis on practice and application, benefits particularly from blended learning models. Studies have shown that implementing flipped classrooms, video tutorials, online laboratories, and interactive in-class activities enhances student engagement, improves academic performance, and develops both technical and soft skills [2, 3]. Furthermore, blended learning supports the adoption of active learning pedagogies, shifting the instructor's role from a transmitter of knowledge to a facilitator of the learning process [4].

Despite its increasing adoption, research on blended learning in engineering education remains underexplored in a systematic manner. Previous studies have often provided valuable case-specific insights, yet the field still lacks a comprehensive, data-driven synthesis to identify research trends, influential contributors, and thematic directions. This study addresses this gap by conducting a bibliometric mapping analysis of 180 peer-reviewed articles published between 2014 and 2024, with data retrieved in June 2025 from two major international databases: Scopus and Education Resources Information Center (ERIC). The combined use of these two databases expands the scope of coverage, reduces indexing bias, and increases the reliability of the analytical results. The novelty of this study lies not only in its broad data coverage and specific focus on the engineering education context, but also in its analytical approach, which is explicitly grounded in key educational frameworks such as the Community of Inquiry (CoI), Constructivism, and Self-Determination Theory (SDT). By integrating trend analysis of publications, keyword networks, authors, countries, and journals with interpretations informed by these theoretical frameworks, the study offers a comprehensive and in-depth overview of the field, while providing practical implications for curriculum development, policy-making, and quality assurance in engineering education in the digital era.

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2. Literature Review

2.1. Definition and Approaches to Blended Learning

Research on blended learning has proposed a variety of definitions, reflecting diverse application contexts and pedagogical objectives. These definitions can be grouped into three main categories:

Pedagogical intent

This group of definitions emphasizes blended learning as an instructional strategy aimed at enhancing learning effectiveness and developing higher-order skills by integrating the strengths of face-to-face and online modes [5, 6]. The core goal is to create an interactive learning environment that supports active and self-directed learning.

Flexibility

Some authors focus on the dimensions of time, location, and pace, suggesting that blended learning allows learners to customize their learning experiences according to individual needs [7]. This is particularly relevant in engineering education, where students need to engage in hands-on laboratory activities while also engaging in self-paced online study.

Instructional design

This perspective defines blended learning as a deliberate instructional design model, in which online and face-to-face activities are intentionally arranged to maximize pedagogical impact [8, 9]. Such design often assigns theoretical content to the online environment, while classroom time is reserved for practice, discussion, and problem-solving.

Although all three categories highlight the integration of two learning modes, they differ in focus and level of detail. In engineering education, the instructional design approach is often considered the most appropriate, as it enables close integration between theory and practice. However, the choice of definition depends on program objectives, learner characteristics, and institutional resources.

2.2. Theoretical Basis for Blended Learning Research

Research on blended learning is often grounded in several key educational frameworks, among which the Community of Inquiry model [10] is one of the most widely used. CoI emphasizes three elements (teaching presence, social presence, and cognitive presence) providing a comprehensive analytical framework that addresses content, interaction, and critical thinking. In engineering education, CoI has been applied to design highly interactive learning activities, such as group projects or online discussions, that foster problem-solving and collaboration skills. In addition, Constructivism [11] posits that learners construct knowledge through experience and interaction; in blended learning, this theory is operationalized through authentic tasks, simulated experiments, and project-based learning, thereby bridging theoretical knowledge with practical application. Furthermore, Self-Determination Theory [12] highlights the roles of autonomy, competence, and relatedness, and blended learning, with its flexibility and capacity for personalization, can effectively meet these needs, encouraging students to take initiative and sustain their motivation.

Although CoI is often described in greater detail than constructivism and SDT, leading to an imbalance in some studies, the three frameworks are complementary, offering multidimensional perspectives on blended learning: CoI focuses on structure and interaction, constructivism emphasizes learning experiences, and SDT explains learner motivation and engagement. Integrating all three provides a comprehensive analytical foundation for understanding the impacts of blended learning on learning outcomes and competency development among engineering students.

2.3. Research Practice on Blended Learning in Engineering Education

In engineering education, empirical studies have implemented blended learning in various forms and intensities, yielding positive outcomes in terms of learning effectiveness, engagement, and skill development. One group of studies focuses on improving academic performance and conceptual understanding. For example, a circuit analysis course applying a flipped classroom model with online lecture videos combined with in-lab practice sessions significantly improved students' exam results and their ability to explain operating principles [13]. These results can be interpreted through the CoI model, where cognitive presence is reinforced by practical activities and direct discussions.

The second group aims to enhance learner engagement and participation. For instance, in a mechanics course, students actively used video tools to revisit challenging topics, pausing and replaying lectures to self-regulate their learning process [10]. This aligns with SDT, where autonomy and competence are supported through control over the pace and mode of content delivery.

The third group focuses on developing professional and soft skills. In the construction field, the implementation of scaffolded video modules alongside in-class problem-solving activities enhanced students' collaboration skills and satisfaction with the course [14]. This reflects the principles of constructivism, where learners build knowledge through experience and social interaction.

However, several challenges have been reported. Increased workload for instructors in designing and managing dual learning environments [15], as well as disparities in digital readiness between individuals and institutions [16], can affect implementation effectiveness. For example, an engineering program at a Southeast Asian university faced difficulties when students in remote areas lacked adequate devices and stable internet connections, leading to inequities in learning experiences [17].

While the evidence demonstrates the potential of blended learning in engineering education, the overall picture of adoption levels, influencing factors, and long-term impacts remains unclear. The fragmentation in approaches and research outcomes, along with the lack of longitudinal data on graduate competencies [18], underscores the need for systematic studies and large-scale data analysis to identify trends and guide strategic directions for the field. Importantly, without such longitudinal and system-level evidence, institutions may struggle to evaluate the sustained effectiveness of blended learning or to align it with competency-based education goals. This gap not only limits the ability to refine instructional design for engineering programs but also hinders the formulation of evidence-based policies that can scale successful practices across diverse institutional and socio-economic contexts.

3. Methodology

3.1. Bibliometric Method and Research Tools

Bibliometrics combines statistical analysis with bibliographic data to explore the development and structure of a research field [16]. Beyond tracking publication counts, it enables researchers to uncover collaboration networks, identify influential authors and institutions, and map thematic trends [17, 18].

This study adopts a bibliometric mapping approach to examine blended learning research in engineering education. Two tools were used. Visualization of Similarities Viewer (VOSviewer v1.6.20) was employed for network visualization, including keyword co-occurrence, co-authorship, and country collaboration maps. Microsoft Excel (2016) was used for data cleaning, trend analysis, and descriptive statistics. These tools were selected for their transparency, reproducibility, and suitability for large-scale mapping [19]. While alternatives such as CiteSpace offer temporal analysis, VOSviewer was prioritized for its ability to generate clear, high-resolution network visualizations that support comparative and structural analysis.

3.2. Data Retrieval

Data collection was conducted in June 2025 from two major databases: Scopus and ERIC. Scopus was chosen for its broad coverage of peer-reviewed literature in engineering and technology, while ERIC specializes in education-focused research.

The Boolean search query was:

("Blended learning" OR "Hybrid learning") AND ("Engineering program" OR "Engineering student" OR "Engineering education" OR "Engineering teaching" OR "Engineering learner" OR "Engineering pedagogy" OR "Engineering curriculum" OR "Engineering training") AND NOT ("online learning" OR "online education" OR "e-learning" OR "distance learning")

Inclusion criteria were:

- Peer-reviewed journal articles in English;

- Published between 2014 and 2024;

- Focused explicitly on blended or hybrid learning in undergraduate or graduate-level engineering education.

Exclusion criteria were:

- Studies limited to fully online or distance learning;

- Non-peer-reviewed sources, conference abstracts, or non-English publications.

3.3. Data Cleaning and Preparation

The initial dataset included 217 records. Duplicates between Scopus and ERIC were identified using DOI matching and removed. The remaining articles were manually screened by reviewing titles and abstracts to ensure relevance, eliminating 37 articles (27 unrelated to the scope, 10 with overlapping research content). This process resulted in a final dataset of 180 articles (169 from Scopus and 11 from ERIC).

Metadata were then normalized to improve consistency. Author names were standardized to merge variations (e.g., “MIT” and “Massachusetts Institute of Technology”), institutional affiliations were harmonized, and country names were aligned with ISO standards. Keywords were cleaned by consolidating synonyms (e.g., “flipped classroom” and “flipped learning”) and removing generic terms such as “case study” [20].

3.4. Data Analysis Strategy and limitations

Analysis proceeded in two stages:

Descriptive analysis (using Excel) examined publication trends, journal distribution, and geographic output.

Bibliometric mapping (using VOSviewer) identified co-authorship patterns, keyword clusters, and country-level collaborations. A minimum occurrence threshold of five was applied for keyword co-occurrence to focus on significant thematic structures.

Each cluster was interpreted in relation to established learning theories (e.g., CoI, Constructivism, SDT) to connect the data-driven findings with relevant pedagogical frameworks.

While bibliometric analysis offers a systematic overview, it has inherent constraints. First, the study relied on indexed articles from Scopus and ERIC, which may underrepresent regional or non-English research.

Second, citation-based measures can be biased toward older publications and well-established authors. Third, VOSviewer's clustering algorithm is data-driven and may overlook emerging but less frequently cited topics. These limitations highlight the importance of complementing bibliometric insights with qualitative or content-based analyses in future studies [21].

4. Results and Discussion

4.1. Trends in Research Development

The analysis of 180 articles published between 2014 and 2024 shows a clear and accelerating growth of research on blended learning in engineering education.

During 2014-2017, annual publications were modest, ranging from 6 to 12 papers, primarily consisting of descriptive studies or small-scale pilot implementations [9, 14]. Interest increased in 2018-2019 as learning management systems (LMS) and interactive tools became more prevalent, and as universities began to adopt learner-centered teaching models [1, 27].

The most significant growth occurred after 2020, coinciding with the COVID-19 pandemic. This period triggered a surge of research into online-offline integration, virtual labs, and technology-enabled assessment [2, 10]. The momentum continued beyond the pandemic, peaking in 2022 with more than 29 articles. Although 2024 shows a slight decline, this is likely due to publication delays rather than reduced scholarly interest.

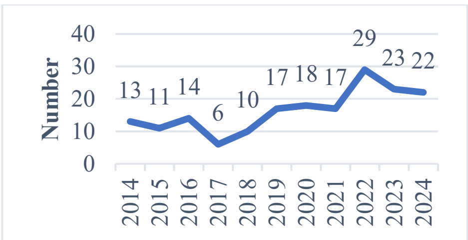

Fig. 1. Publication trend by year

As shown in Fig. 1, these trends underscore a shift in blended learning from a supplemental teaching strategy to a sustainable educational model. Importantly, recent studies increasingly address specialized topics such as learning analytics, AI-assisted course design, and longitudinal tracking of student outcomes, reflecting the field's maturation and its alignment with broader educational reforms.

4.2. Keyword Co-occurrence and Thematic Clusters

From the dataset of 180 articles, more than 1,000 unique keywords were extracted from both Author Keywords and Index Keywords, then standardized by merging synonyms (e.g., "flipped classroom" and "flipped learning") and removing overly generic terms (e.g., "case study", "implementation").

Table 1. Top 30 most frequent keywords in blended learning research in engineering education (2014–2024)

Rank	Keyword	Freq.	Rank	Keyword	Freq.
1	blended learning	147	16	assessment	11
2	engineering education	95	17	surveys	11
3	students	57	18	technology-enhanced learning	10
4	teaching	33	19	hybrid course	9
5	learning systems	25	20	learning analytics	9
6	flipped classroom	24	21	covid-19	8
7	active learning	22	22	e-learning tools	8
8	higher education	19	23	online laboratories	7
9	project-based learning	18	24	active engagement	7
10	online learning	17	25	digital learning	7
11	motivation	15	26	learning outcomes	6
12	collaborative learning	14	27	pedagogy	6
13	learning environment	14	28	problem-solving	6
14	curriculum	13	29	instructional design	5
15	performance	12	30	course design	5

Table 1 presents the 30 most frequent keywords in the dataset. As expected, blended learning and engineering education appear as the top two terms, which is a direct consequence of their inclusion as mandatory search parameters during data retrieval. Their high frequency therefore reflects dataset construction rather than thematic dominance.

For further analysis, the study focused on keywords from rank 3 and below. Students (rank 3) appeared in 57 articles, often associated with topics of learning engagement, learning outcomes, and learner experiences. Teaching (rank 4) and learning systems (rank 5) reflected the continued interest in pedagogical strategies and technological infrastructure. Terms such as flipped classroom, active learning, learning environment, curriculum, performance, motivation, and collaborative learning showed a diversity of research approaches and goals. This result is consistent with the analysis of the keyword co-occurrence map in Fig. 2, which was built using VOSviewer (minimum occurrence threshold of 5). The map is divided into 5 color clusters with typical themes as shown in Fig. 2.

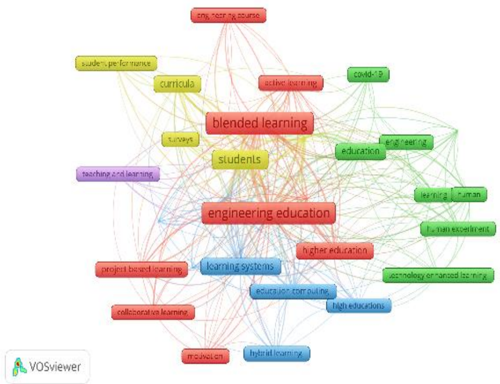

Fig. 2. Keyword co-occurrence visualization map (extracted from VOSviewer)

Cluster 1 (red, 9 keywords) – Focuses on core pedagogical models and course design, including *blended learning, engineering education, flipped classroom, active learning, collaborative learning, project-based learning*, and supporting factors such as *motivation* and *higher education*. This cluster reflects the main research direction on innovation in teaching methods with learners as the center.

Cluster 2 (green, 8 keywords) – Relates to learning environment and conditions, including *learning environment, technology enhanced learning, covid-19, education, engineering, human, human experiment, learning*. This cluster emphasizes the role of technology infrastructure and human factors.

Cluster 3 (blue, 7 keywords) – Focuses on training support systems and tools, including *learning systems, blended learning environment, learning environments, hybrid learning, education computing, computer aided instruction, high educations*. This cluster reflects research on technology platforms and solutions.

Cluster 4 (yellow, 5 keywords) – Relates to learning outcomes assessment and program design, including *students, curriculum, student performance, surveys, teaching*. This cluster emphasizes studies that measure learning outcomes and improve programs.

Cluster 5 (purple, 1 keyword) – Includes only *teaching and learning*, reflecting a general theoretical approach, with little direct connection to specialized technical terms. Although small in scale, this cluster still shows the existence of studies that approach the topic from a general perspective.

The formation of these five clusters reflects the knowledge structure of the blended learning field in engineering education, showing that blended learning is not just a single method but a multidimensional ecosystem that combines pedagogical innovation, technology integration, assessment improvement, and industry-specific applications. A clear understanding of these clusters helps guide future research, such as developing a Blended Learning model that more closely links pedagogical innovation and competency assessment, or enhancing the integration of technology into real-world learning situations in the industry.

Combining keyword frequency data (Table 1) and keyword network analysis (Fig. 2) allows for both quantitative aspects and relationships between topics to be compared. The similarity between high-frequency keywords and keyword cluster structures strengthens the reliability of the results, while also pointing out gaps such as socio-emotional factors and system-level research, which are still underexplored in the context of engineering education.

4.3. Journals and Publishing Landscape

Identifying the top journals helps to identify the academic community and the publication ecosystem.

Table 2. Top 10 journals with the most articles on blended learning in Engineering Education (2014–2024)

Rank	Journal	Publishing House	No. of articles
1	Advances in Engineering Education	American Society for Engineering Education	10
2	International Journal of Engineering Education	Tempus Publications	9
3	Computer Applications in Engineering Education	John Wiley and Sons Inc	9
4	Journal of Engineering Education Transformations	Rajarambapu Institute of Technology	8
5	Computers in Human Behavior	Elsevier Ltd	5
6	Education Sciences	MDPI	5
7	European Journal of Engineering Education	Taylor and Francis Ltd.	4
8	International Journal of Emerging Technologies in Learning	Kassel University Press GmbH	4
9	Internet and Higher Education	Elsevier Ltd	3
10	International Journal of Engineering Pedagogy	International Association of Online Engineering	3

As shown in Table 2, Advances in Engineering Education leads with 10 articles, followed closely by the International Journal of Engineering Education and Computer Applications in Engineering Education (both with 9 articles), followed by the Journal of Engineering Education Transformations (8 articles). These are all journals with strengths in engineering education, regularly publishing innovative research on teaching methods, including blended learning.

In addition, educational technology journals such as Education Sciences, Computers in Human Behavior, and International Journal of Emerging Technologies in Learning also contribute significantly, reflecting the interdisciplinary nature of the topic - both linked to the engineering context and strongly influenced by educational technology advances. However, there is a lack of presence of journals from the Southeast Asian region or emerging publishing channels, indicating a gap in geographical diversity in the field's publishing landscape.

4.4. Influential Authors, Institutions, and Citation Metrics

Data analysis shows that the authors with the most publications on blended learning in engineering education are concentrated at a few leading research institutions (Table 3). Evenhouse D., Berger E., Rhoads J.F. and DeBoer J. (Purdue University, USA) lead with 4 publications each, while Moll-López S. (Universitat Politècnica de València, Spain) is next with 3 publications. These are institutions with long-standing strengths in engineering education and innovation in teaching methods.

When considering academic impact, as measured by citation counts, a clear disparity emerges. Moll-López S. (160 citations) and Moraño-Fernández J.A. (149 citations) have significantly higher citation metrics compared to other highly productive authors. This indicates that "influence" depends not only on the number of publications but also on the quality and reach of each work.

This pattern highlights the multidimensional nature of "influence" in blended learning research within engineering education. While institutions such as Purdue University maintain consistent productivity, the exceptionally high citation counts of authors like Moll-López S. and Moraño-Fernández J.A. indicate that targeted, high-impact studies can shape the discourse as much as, or even more than, prolific output. These findings emphasize the need to combine both productivity and citation metrics when assessing influence, and underscore the role of international collaborations and cross-institutional networks in enhancing research visibility and impact.

Table 3. Top 10 authors, institutions, number of articles and number of citations

Rank	Author	Affiliation	Publications	Citations
1	Evenhouse D.	Purdue University, USA	4	54
2	Berger E.	Purdue University, USA	4	54
3	Rhoads J. F.	Purdue University, USA	4	54
4	DeBoer J.	Purdue University, USA	4	54
5	Moll-López S.	Universitat Politècnica de València, Spain	3	160
6	Daly S. R.	University of Michigan, USA	2	8
7	Moraño-Fernández J. A.	Universitat Politècnica de València, Spain	2	149
8	Pudumalar S.	Hindustan Institute of Technology and Science, India	2	6
9	Pérez-Sanagustín M.	Institut de Recherche en Informatique de Toulouse (IRIT), France	2	84
10	Liu Z.	Southern University of Science and Technology, China	2	15

4.5. Country-Level Distribution and Collaboration

The top ten countries with the highest number of publications show marked differences between research output, citation levels and international collaboration intensity (Table 4).

The data were extracted from VOSviewer using a minimum threshold of five publications on Scopus and ERIC during 2014-2024. Citation counts and Total Link Strength (TLS) were calculated based on the number and intensity of international co-authorship links. Therefore, this table includes only countries that meet both productivity and connectivity thresholds, while some countries with collaborative activity but fewer outputs are not listed.

Table 4. Number of publications and citations of the top 10 countries (2014-2024)

Rank	Country	Documents	Citations	Total link strength
1	USA	24	866	11
2	Spain	19	476	6
3	India	16	40	1
4	China	13	65	4
5	UK	13	973	9
6	Australia	9	825	6
7	Indonesia	9	151	1
8	Malaysia	8	150	5
9	Mexico	7	23	2
10	Russia	6	26	1

The results reveal marked disparities between research output, academic impact, and collaboration intensity. The USA leads in all three indicators, with 24 publications, 866 citations, and TLS of 11, reflecting its central role in the global network. The UK achieves the highest citation count (973) and TLS of 9 despite producing the same number of publications as China (13), indicating a strategy focused on publishing in high-impact journals and fostering extensive collaboration. Australia maintains similar efficiency with nine publications, 825 citations, and a TLS of 6.

In contrast, India and Indonesia both have relatively high outputs (16 and nine publications, respectively) but very low citations (40 and 151) and TLS values of only 1, reflecting limited dissemination and international collaboration. Possible causes include language barriers, publication policies favoring local conferences, or a concentration on niche topics with limited citation potential. China (65 citations, TLS equal to 4) and Malaysia (150 citations, TLS equal to 5) show potential to enhance their influence by expanding collaborations beyond their regions.

Developing countries such as Indonesia, Malaysia, Mexico, and Russia are present in the top 10 but rank lowest in citations and TLS, highlighting gaps in academic connectivity. These gaps not only reflect imbalances in research resources and technological infrastructure but also limit participation in large-scale international projects, thereby constraining the field's overall impact.

This finding reinforces the analysis in Section 4.4 on influential authors, showing that countries with highly cited authors (USA, UK, Australia) are also central hubs for international collaboration, underscoring the link between research quality and network strength. Referring to the theoretical frameworks in Section 2.2, particularly the Community of Inquiry and Self-Determination Theory, it becomes clear that countries maintaining broad collaborative networks are better positioned to share knowledge, develop resources, and foster highly interactive blended learning environments. The implication for future research is the need to promote interregional collaboration and support emerging countries in joining global research networks through joint projects, open data sharing, and publication in high-impact journals.

5. Discussion

This study provides a comprehensive picture of the development of blended learning in engineering education, based on the analysis of 180 articles from 2014–2024. The results from sections 4.1–4.5 reveal both significant progress and gaps that need to be addressed, when viewed in terms of trends, research content, publication ecosystem, authors, and countries of influence.

5.1. Development Trends and Contextual Impact

The data in Section 4.1 show a strong growth in publications after 2020, linked to the impact of the COVID-19 pandemic and the digital transformation of education. The shift from experimental models to sustainable implementation strategies reflects the high adaptability of the field. However, the slight decline in 2024 suggests that the publication cycle is influenced by publication lags rather than declining interest. This highlights the need for longitudinal research to assess the sustained impact of blended learning, rather than just relying on fluctuating points in time.

5.2. Research Content: Strong in the Classroom, Weak at the System Level

A key word and theme cluster analysis (Section 4.2) shows that research focuses on classroom strategies – such as flipped classrooms, project-based learning, active learning - and student experience and motivation factors. These have proven effective in improving engagement and short-term learning outcomes. However, macro-level topics such as curriculum architecture, institutional policies, links to quality assurance frameworks or employability competencies are rare. This gap limits the ability to link research to education reform and national policy, consistent with the reviewer's comments on the lack of linkages between theory and practice at the system level.

5.3. Publication Ecosystem: Lack of Geographical Diversity and Publication Channels

Section 4.3 points to the concentration of specialist journals in the US and Europe, with a lack of publication channels from Southeast Asia or emerging markets. This reflects not only the dominance of major academic centres, but also the barriers to indexing, language and publishing strategies in developing countries. As a result, the voices of local contexts are not fully reflected in the international discourse.

5.4. Authors, Institutions, and Countries of Influence: the Relationship between Output, Quality, and Collaboration

The data in section 4.4 and section 4.5 show that a few institutions such as Purdue University or Universitat Politècnica de València, and countries such as the US, UK, Australia and Spain, have both high output and outstanding citation indices and TLS. In contrast, some countries (India, Indonesia) publish a lot but have low citations and TLS, reflecting limited collaboration and dissemination of results. This gap is consistent with the reviewer's comments on the fragmentation of the collaboration network and the lack of cross-regional comparative research.

5.5. Links to Theoretical Frameworks

The above results are consistent with the Community of Learning model, where international collaboration plays a role in enhancing teaching, social and cognitive presence. Constructivism reinforces the role of diverse collaboration in effective knowledge creation, while Self-Determination Theory explains how expanded collaboration promotes autonomy, competence, and connectedness of both faculty and students. The fact that countries and institutions that are central in the collaboration network often have high impact indicators is a clear demonstration of these principles.

5.6. Implications for Research and Practice

The findings from sections 4.1 to 4.5 suggest that the research direction needs to be expanded from single case studies to longitudinal, multi-institutional designs to assess the long-term impact of blended learning on graduate competencies and employability of students. In addition, the research content needs to be expanded to the system level, closely linked to quality assessment, curriculum reform and national standards frameworks, to ensure the sustainability and replicability of the model.

Diversifying publication channels, especially encouraging the presence of academic journals and conferences from developing regions, will contribute to creating a more comprehensive research picture. More importantly, it is necessary to promote cross-regional cooperation, connecting influential research centers with emerging countries through joint projects, open data initiatives and co-authored publications in prestigious journals. These orientations not only bridge the gap in resources and influence, but also contribute to the formation of a globally integrated, cohesive, and clearly oriented blended learning research ecosystem for engineering education policy and practice.

6. Conclusion

This study conducted a bibliometric analysis of 180 scientific articles from 2014–2024, providing a comprehensive picture of the development of blended learning in engineering education. By combining trend nalysis, keywords – topic clusters, publication ecosystem, authors, and countries of influence, the study not only summarizes the formation and expansion of the field but also points out notable gaps.

The results show that blended learning is shifting from a complementary model to a sustainable implementation strategy, with strong growth after the COVID-19 pandemic. The current research content focuses more on teaching strategies and student experiences, while system-level issues such as program architecture, institutional policies, quality assurance, and long-term impact on graduate capacity have not been fully exploited. The publication ecosystem lacks geographical diversity, with a few academic centers in the US and Europe dominating. High publication output does not necessarily mean high impact; countries with high levels of international collaboration often achieve superior citation impact, emphasizing the key role of academic connections.

Linked to the theoretical frameworks of Community of Inquiry, Constructivism and Self-Determination Theory, the study shows that international collaboration not only improves pedagogical quality but also strengthens the motivation and sustainability of blended learning environments. This suggests future directions for development: expanding longitudinal and multi-institutional research to assess long-term impact; integrating research into accreditation frameworks, curriculum reform, and quality standards; diversifying publication channels; and enhancing inter-regional cooperation, connecting leading research centers with emerging countries.

With a systematic and data-driven approach, this study not only synthesizes and positions blended learning in the global engineering education context, but also provides clear direction for researchers, managers, and policy makers to promote this model as a core, effective, and sustainable component of engineering education in the digital age.

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