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Trends and Developments in Engineering Education: A Bibliometric Analysis of Students' Competencies Research (2015-2024)

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Abstract: In this study, CiteSpace and VOSviewer bibliometrics software were used to analyze 257 papers on the topic of student competencies in engineering education included in the Core Collection of Web of Science databases from 2015 to 2024, revealing the research hotspots and development trends in this field. The study found that innovative research in engineering education mainly focuses on the areas of interdisciplinary integration, technology application and sustainable development, especially the application of project- based learning (PBL), augmented reality (AR) technology, and modeling tools have shown significant results in enhancing students' practical ability and innovative thinking. the extensive application of models such as BIM and LCSD further enhances students' professional skills in system analysis and engineering design. Meanwhile, the innovative curriculum design and the cultivation of innovative self-efficacy played an important role in the development of students' creativity. This study not only summarizes the hotspots of existing research, but also proposes future research directions in technology integration, global competency development and social responsibility education, providing a strong theoretical basis for the future development of engineering education.

Keywords: Engineering Education; Student; Innovation Ability; Interdisciplinary Integration; Project-Based Learning (PBL); Student; Sustainability; Global Competence Cultivation.

1. Introduction

Engineering education has become a crucial field of research due to its significant role in driving technological innovation, economic growth, and addressing global challenges. As the world increasingly relies on technological advancements to solve complex issues related to infrastructure, the environment, and sustainability, the education of future engineers is of paramount importance. Engineering education equips students with the necessary technical skills and problem-solving abilities, enabling them to design, build, and maintain the systems and structures upon which modern society depends. In this context, conducting a bibliometric analysis of international trends and developments in engineering education from 2015 to 2024 provides valuable insights into how educational practices are evolving to meet the rapidly changing demands of the world.

Scholars have extensively explored various aspects of engineering education, with a focus on curriculum development, teaching methods, and the integration of emerging technologies. Recent research highlights a shift towards interdisciplinary education and an increased emphasis on project-based learning to foster innovation and creativity among engineering students. Studies also underscore the need for flexibility and globalization in engineering projects to enhance students' mobility and adaptability in the global job market. Furthermore, the adoption of virtual and augmented reality technologies, along with artificial intelligence, is identified as key trends in modern engineering education[1].

However, most current research focuses on isolated aspects of engineering education, failing to provide a comprehensive overview of global trends and their impacts. Additionally, there is a lack of systematic bibliometric analysis to quantitatively assess the evolution of engineering education research over the past decade. This study aims to fill these knowledge gaps by systematically exploring and integrating relevant literature on engineering education indexed in the Web of Science. The objective is to analyze the current state of the research field, its thematic evolution, and the factors shaping its development trajectory. This study is guided by three research questions.

1) What are the global trends in engineering education from 2015 to 2024?
2) How can fragmented insights from specific areas of engineering education be synthesized into a coherent understanding?
3) How have the focus and themes of engineering education research evolved over the past decade?

By addressing these questions, this study aims to contribute to the literature by providing a comprehensive and systematic overview of international trends and developments in engineering education, thereby informing future research and educational practices.

2. Methodology

This study employs a bibliometric approach, which is defined as "a discipline that applies mathematical and statistical methods to analyze the distribution and characteristics of scientific and technological literature" [2]. This method collects relevant literature data from scientific databases such as Web of Science and Scopus, including information such as paper titles, abstracts, authors, publication years, and citation counts. The literature is filtered based on the research topic and keywords, excluding irrelevant or low-quality studies to ensure the accuracy and relevance of the analysis. Bibliometric tools such as VOSviewer and CiteSpace are used to process the data, generating visual charts such as co-word analysis maps, co-citation networks, and author collaboration networks. By analyzing these charts, researchers can uncover trends, research hotspots, key authors, and major research institutions in the field, thereby formulating more scientifically sound research strategies [3]. Bibliometrics allows for an objective and quantitative evaluation of the literature, reducing subjective bias in the assessment process and increasing transparency and fairness in the evaluation [4].

3. Data Sources

The data for this study were sourced from the Web of Science Core Collection, a digital literature resource database considered to be the most suitable for bibliometric analysis [5]. The Web of Science covers a wide range of publications across various fields [6]. For literature retrieval, SCI-EXPANDED and SSCI were selected to ensure comprehensive and accurate data. The search strategy was defined as TS=("engineering education" and "ability" or "competencies" or "skills"), with a time span starting from January 2015 to January 2024, and the retrieval was conducted by January 1, 2024. The document types were limited to Articles and Review Articles. After deduplication, 388 journal papers were obtained, and after further screening, 257 valid papers were selected.

Table 1. Summary of data source and selection

Category	Specific Standard Requirements
Research database	Web of Science
Citation Indexes	SSCI
Searching Period	JAN 2015 TO JAN 2024
Language	English
Searching keywords	" Engineering education "and " ability " or " competencies " or " skills"
Document types	Article and Review article
Data extraction	Export with full records and cited references in plain text format
Sample size	388

4. Findings

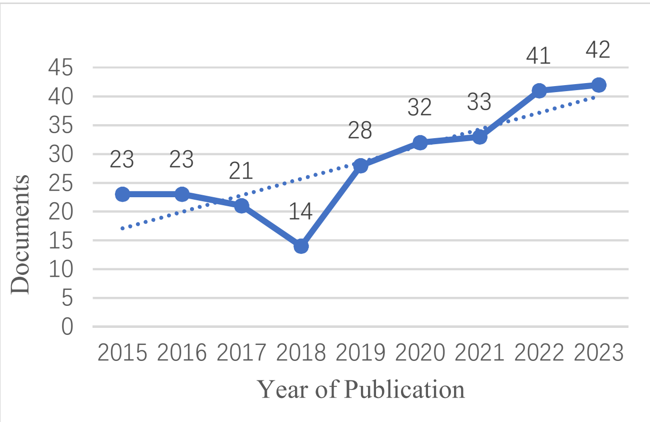

Figure 1. Chart of Annual Publication Volume

The 257 papers used in this study were authored by 971 researchers from 369 institutions across 59 countries and were published in 55 journals. These papers cited a total of 11,498 references from 6,242 different journals. A year-wise distribution chart of the number of published papers was generated for this study (Figure 1). As shown in the figure, since 2014, the number of publications on the topic of student competency development in engineering education has exceeded 20 papers per year, with a noticeable upward trend. This indicates that research in this field has garnered increasing attention from international scholars.

4.1. Analysis of High-Publication Countries/Regions

To better understand the distribution of high-publication countries/regions, 257 data entries were imported into VOSviewer, with the node type set to "Country." In the generated visualization map, larger nodes indicate that a country/region has published more papers related to the theme of competency development in engineering education. As shown in Figure 2, the top four countries/regions in terms of the number of publications are the United States, China, Spain, and the United Kingdom.

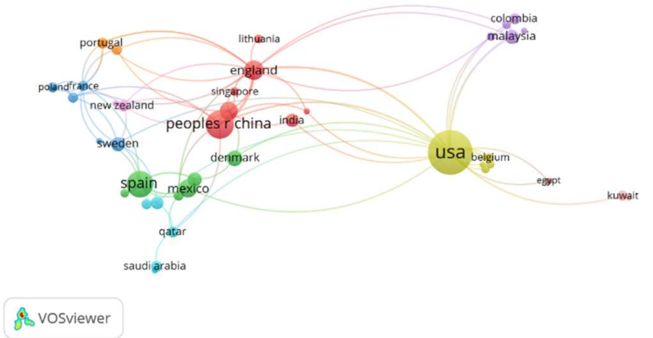

Figure 2. Highly documented areas

Table 2 shows the top 10 countries/regions by the number of publications. The United States ranks first, with 91 papers, accounting for 35.4% of the total publications, and a total of 1,157 citations, far surpassing other countries. China and Spain follow with 43 and 29 papers, accounting for 16.73% and 11.28% of the total publications, respectively. Mexico has the highest average citation rate per paper, reaching 16.67. Notably, China ranks second among the top publishing countries/regions, with 43 papers and 280 citations.

Table 2. High-volume countries/areas (top 10)

Rank	Countries	Count	Citations	Average Citation/Publication
1	USA	91	1157	12.71
2	PEOPLES R CHINA	43	280	6.51
3	SPAIN	29	304	10.48
4	ENGLAND	14	168	12.00
5	MEXICO	12	200	16.67
6	AUSTRALIA	11	172	15.64
7	BRAZIL	9	27	3.00
8	DENMARK	8	124	15.50
9	CHILE	7	32	4.57
10	MALAYSIA	7	87	12.43

4.2. Analysis of Publishing Institutions

Table 3 shows that there are 9 institutions with more than three publications. The top three institutions are Purdue University (12 papers), Penn State University (10 papers), and Arizona State University (8 papers), all from the United States, along with Universidad Politécnica de Madrid (8 papers). It is noteworthy that U.S. universities contributed 44 papers, accounting for 64.7% of the publications from high-output institutions, highlighting the United States as the country with the highest global influence in this field. In terms of the average citation rate per paper, Spain's Universitat Politècnica de Catalunya stands out with 57.14 citations per paper, followed by the Georgia Institute of Technology in the U.S., with an average of 16.67 citations per paper.

Table 3. Table of Publishing Institutions Statistics

Rank	Organization	Documents	Citations	Average Citation/Publication
1	PURDUE UNIV	12	101	11.88
2	PENN STATE UNIV	10	145	6.90
3	ARIZONA STATE UNIV	8	60	13.33
4	UNIV POLITECN MADRID	8	68	11.76
5	TECNOL MONTERREY	7	161	4.35
6	TEXAS A&M UNIV	5	74	6.76
7	VIRGINIA TECH	5	91	5.49
8	AALBORG UNIV	5	94	5.32
9	UNIV POLITECN CATALUNA	4	7	57.14
10	GEORGIA INST TECHNOL	4	24	16.67

4.3. Analysis of High-Publication Authors

Among high-productivity authors, the most-cited is Gurcan from Karadeniz Technical University, Department of Computer Engineering, who has published 3 papers between 2015 and January 2024, with a total of 99 citations, averaging 33 citations per paper. In 2019, Gurcan used Latent Dirichlet Allocation (LDA) to analyze online job advertisements, revealing the core competencies and skills required in big data software engineering. He also provided recommendations for education and training to bridge the gap between industry demands and engineering education programs.

The second-highest is Miller from the School of Social Work at the University of Georgia, USA. His 3 papers have received a total of 79 citations, with an average of 26.22 citations per paper. Miller emphasized the importance of fostering creativity in engineering education[7], and highlighted how individuals' attitudes toward risk and creative confidence significantly influence idea generation and selection in engineering education [8].

Table 4. Top 10 Author in Engineering students' competency research

Rank	Author	Documents	Citations	Average Citation/Publication
1	Gurcan,fatih	3	99	33.00
2	Miller,scarlett r.	3	79	26.33
3	Holgaard,jette egelund	3	75	25.00
4	Iopez,david	3	51	17.00
5	Martin,carme	3	45	15.00
6	Godwin,allison	3	29	9.67
7	Zhang,jingxiao	3	23	7.67
8	Berdanier,catherine g.p.	3	19	6.33
9	Carberry,adam r.	3	19	6.33
10	Benedict,brianna	2	28	14.00

5. Analysis of Research Hotspots

Keywords distill the core and essence of a paper, and through co-occurrence analysis of keywords, research hotspots in a scientific field can be identified. Using VOSviewer, a keyword co-occurrence network view was generated for the 257 papers, selecting 26 key keywords with a frequency of 8 or more for visualization. As shown in Figure 3, the larger the circular node, the more frequently the keyword appears, making it more representative of the field's hotspots. The lines between the nodes represent the strength of association; the thicker the line, the more frequently the two keywords co-occur in the same paper. The color of the nodes represents different clusters, indicating distinct research themes. To more clearly understand the research hotspots in the field of student competency development in international engineering education, 257 data entries were imported into VOSviewer, and the keywords were clustered. A co-occurrence frequency of 5 was chosen, and overly broad keywords such as "engineering education" and "education" were excluded. This resulted in four clusters of high-frequency keywords (as shown in Figure 3).

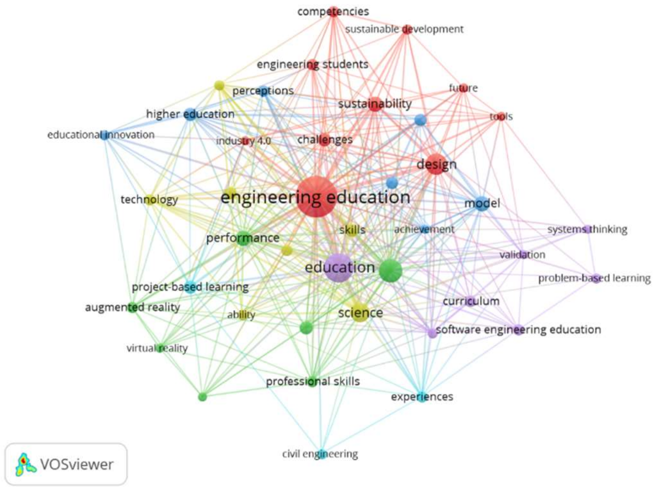

Figure 3. Co-occurrence of keywords

Table 5. Cluster of keywords in International Engineering Education Research field

Cluster	Color	Keywords
1		competencies, engineering students,framework, perceptions, project-based learning,science, skills, sustainability, technology
2		curriculum,design,students,experiences,professional skills,software engineering education
3		Augmented reality, challenges, knowledge, performance, engineering-education
4		creativity, innovation, model

Cluster 1 focuses on how project-based learning (PBL) and sustainability education can enhance engineering students' skills, practical abilities, and innovation awareness. Rendón-Castrillón et al. (2023) applied PBL methods in a chemical engineering course by integrating bioprocess research into teaching, significantly improving students' professional abilities in areas such as experimentation, communication, and knowledge acquisition. This teaching approach not only boosted students' hands-on skills in real-world projects but also enhanced their understanding of sustainability issues, fostering their innovation and problem-solving abilities. Similarly, El-adaway et al. (2015) found that combining service learning (SL) with PBL effectively improved students' learning outcomes in sustainable construction projects. Other studies, such as that of Ariza & Olatunde-Aiyedun (2023), demonstrated the effectiveness of PBL in renewable energy education, proving the method's success in addressing complex technical challenges. Furthermore, Coronado et al. (2021) noted that, in the long-term application of PBL in civil engineering education, students widely acknowledged the method's effectiveness in improving teamwork, communication, and leadership skills. In terms of sustainability education, Winkens & Leicht-Scholten (2022) highlighted the importance of social responsibility in sustainable engineering design, emphasizing that future engineers need not only technical skills but also the ability to understand social and sustainable design aspects. Sánchez-Carracedo et al. (2021) developed three tools to integrate Sustainable Development Goals (SDGs) into engineering courses, providing a method to assess students' sustainability knowledge. These studies collectively indicate that the integration of sustainability education and PBL in engineering education effectively cultivates students' professional abilities, social responsibility, and innovation skills.

Cluster 2 focuses on the development of "design," "professional skills," and "curriculum design," closely integrating students' learning experiences with the practical application of engineering education. Sánchez Carracedo et al. (2018) incorporated design concepts into the curriculum by creating a "competency map," clearly defining the design skills students need to master in engineering projects, ensuring the systematic and comprehensive nature of design education. Amelkina et al. (2022) emphasized the practical role of engineering design competitions in developing students' design skills, noting that these competitions help bridge theory and practice, enhancing students' ability to solve real-world problems and improving their design literacy. Meanwhile, Tseng et al. (2019) applied the CDIO (Conceive-Design-Implement-Operate) teaching model in a mold design course, integrating real design projects into the curriculum to help students enhance their professional skills through practice. Similarly, Castelló et al. (2023) improved students' professional abilities by incorporating design-related projects and real industry cases in chemical engineering education. These studies collectively underscore the importance of combining "design tasks" with "professional skills" in curriculum design to help students acquire practical skills in simulated engineering environments. Lattuca et al. (2017) proposed a curriculum design framework focused on design thinking and professional skills, which equips students with design capabilities in interdisciplinary fields and enables them to apply these skills to real-world problems. Franco et al. (2023) further proposed a competency-based teaching framework, highlighting the importance of curriculum design in developing students' professional abilities, particularly through the integration of social responsibility and technical development in innovative education models.

Cluster 3 centers on the application of emerging technologies like augmented reality (AR) in engineering education and their potential to enhance students' visual comprehension and engineering knowledge. Hernández et al. (2023) indicated that AR technology, through its provision of three-dimensional interactive and real-time environments in engineering labs, significantly improves students' understanding of complex technical concepts and spatial skills. Additionally, Gutiérrez et al. (2015) emphasized the advantages of AR in facilitating autonomous learning of equipment operation and processes, helping students better grasp practical engineering skills. Tan et al. (2024) further pointed out that AR technology enhances students' memory and comprehension, particularly when abstract technical content is presented, greatly improving their learning outcomes. These studies collectively demonstrate that AR technology not only plays a supportive role in engineering education but also enhances students' understanding and application of complex engineering concepts, reflecting the growing importance of educational technology in engineering education.

Cluster 4 focuses on innovation in engineering education. Research on innovation in engineering education continues to expand across multiple dimensions, including teaching methods, technological tools, and curriculum design, with particular attention to the role of model applications in educational innovation. Challenge-based learning (CBL) and project-based learning (PBL) have been shown to effectively stimulate students' innovative thinking and practical skills. Through real engineering projects and industry collaboration, students' teamwork and creativity have been significantly enhanced [24][25]. At the same time, the introduction of augmented reality (AR) technology provides innovative tools for teaching, allowing students to gain a deeper understanding of complex engineering concepts in virtual environments, thereby improving self-directed learning and problem-solving abilities[21]. The application of models has also become an important aspect of educational innovation. Studies have shown that the use of models such as BIM technology and LCSD simulation tools in courses significantly enhances students' system analysis and engineering design skills [27]. Additionally, innovative course design and the cultivation of innovation self-efficacy are seen as key factors in fostering students' creativity. Systematic course frameworks and assessment tools have been shown to effectively stimulate students' innovative potential [28][29]. Overall, innovation in engineering education is being driven by diverse teaching strategies, the application of technology, and the integration of models, which comprehensively enhance students' innovation capabilities and practical skills, laying a strong foundation for cultivating future engineers with forward-looking and comprehensive abilities.

6. Research Trends

Future research in engineering education will place greater emphasis on the integration of students' interdisciplinary skills and sustainability, exploring how project-based learning (PBL), augmented reality (AR) technology, and innovative educational models can cultivate students' comprehensive abilities and social responsibility. Further research into the integration of sustainability and technology applications will become a key direction for enhancing students' engineering practice capabilities. This is particularly relevant in the context of global challenges and complex engineering problems, where the interaction between PBL and sustainability education will be of significant importance. Additionally, with the aid of augmented reality and virtual reality technologies, engineering education will continue to promote the visualization and interactivity of teaching experiences, thereby enhancing students' understanding and application of abstract engineering concepts.

At the same time, future research should delve deeper into how design thinking and innovation can be fostered to create curriculum designs and teaching strategies that are adaptable to the rapidly evolving engineering technology landscape. On the other hand, research trends will also focus on the cultivation of students' social responsibility and global competence, exploring how to effectively integrate social and environmental issues into the curriculum. This will guide students to develop a sense of social responsibility and sustainability awareness in engineering practice. By examining the connection between engineering education and professional skills, future research will increasingly focus on cultivating engineers with a global perspective and innovative capabilities in diverse cultural and technological contexts.

7. Conclusion

Overall, engineering education has shown a trend toward interdisciplinary integration, innovative teaching models, and sustainability over the past decade in cultivating students' competencies. Research hotspots have primarily focused on enhancing students' practical abilities, professional skills, and innovation awareness through methods such as project-based learning, augmented reality technology, and design thinking. The development of student competencies has gradually shifted from single-skill training to comprehensive ability development, with an emphasis on students' social responsibility and global competence. This shift reflects engineering education's ongoing efforts to address the complex challenges of modern society and technological innovation, laying a solid foundation for cultivating high-quality talent capable of adapting to the future engineering environment.

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