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PAPER

Emerging Engineering Education in China: A Systematic Literature Review

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ABSTRACT

This systematic literature review (SLR) delves into current research trends and challenges in articles related to China's Emerging Engineering Education (EEE), as indexed by the Web of Science (WOS). This study focuses on three significant research questions: 1) What are the current research trends based on existing literature? 2) What is the current development status of China's emerging engineering disciplines? and 3) What are the future research directions? In examining the current development status of China's EEE, this study reviewed topics such as the development of EEE policy and practice teaching, as well as related challenges and issues. The future research directions suggested in this study emphasize the significance of the institutionalization of Emerging Engineering Research (EER), fostering collaborative networks and global dialogues, bridging the gap between theoretical research and practical applications, embracing innovative models and practices, integrating new principles into curricula, evaluating educational interventions and programs, and exploring interdisciplinary approaches. This review provides insights into the current state of engineering education in China and highlights future research directions to address new challenges and opportunities in this field.

KEYWORDS

systematic literature review (SLR), Emerging Engineering Education (EEE) initiative, China, Web of Science (WOS)

1 INTRODUCTION

Engineering education in China is currently experiencing significant changes, driven by national policies and strategic initiatives. The Chinese Ministry of Education has introduced the Emerging Engineering Education (EEE) initiative, a three-stage sequential policy designed to reform engineering education in response to the growing enrollments and the need for educational reforms [1]. This initiative aims to meet the evolving demands of the engineering field and ensure that educational programs is aligned with industrial needs.

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However, the 20th Central Committee's Third Plenary Session in 2024 further reinforced the strategic positioning of education, science and technology, and human resources, proposing to strengthen these fields as fundamental and strategic supports for Chinese-style modernization [2]. The spirit of the plenum advocates for a more systematic approach to education reform, centered on the new engineering disciplines, to improve the overall efficacy of the national innovation system and foster the development of high-quality talent. After a seven-year hiatus, the Third Plenary Session of the 20th CPC Central Committee set a new course for the depth and growth of the NIE in order to better adapt to the rapidly changing scientific and technical environment, while addressing the challenges of globalization. These reforms focus on strengthening the country's strategy by optimizing the education system, advancing China's engineering education to align with the global innovation system, and cultivating high-quality talent to address the demands of Industry 4.0 and emerging sectors within the digital economy [3].

Furthermore, the EEE initiative, launched in 2017, is transforming Chinese engineering education by restructuring programs and redesigning curricula to be more interdisciplinary and future-oriented [4]. This initiative signifies a strategic step towards preparing students for emerging technologies and global challenges, underscoring the importance of keeping up with technological advancements and industry trends. EEE holds particular significance for China due to various factors. The country recognizes the need for reform in engineering education to address the challenges posed by the evolving scientific and technological landscape [5]. The importance of EEE in China also lies in its role in propelling technological advancement, nurturing innovation, and equipping individuals with the necessary skills to excel in a rapidly evolving global environment.

Industry 4.0 has catalyzed the emergence of new sectors within the digital economy. To sustain economic growth, China requires a greater number of skilled talents to drive core technological developments. These developments not only impose new demands on the skill sets of the workforce but also present additional requirements for university education. However, cultivating high-quality professionals to meet industry requirements has proven to be a daunting task. Enhancing the employability of university students therefore necessitates a reform of traditional engineering education, grounded in pertinent educational paradigms. The level of higher education represents a crucial asset for a country. Since February 2017, the Ministry of Education in China has been actively promoting EEE to cope with the new technological revolution and Industry 4.0 reform. According to the plan of the Ministry of Education, a world-class engineering education system is set to be established in 2030 [6]. Since February 2017, the ministry has also promoted the development of initiatives such as the formation of the "Fudan Consensus," "Tian da Action," and "Beijing Guidelines" on new engineering fields [7]. The ministry has also issued the Notice on Research and Practice in New Engineering and the Notice on Promoting Research and Practice Projects in New Engineering [7]. Numerous universities in China have embarked on educational reforms in line with the principles of Emerging Engineering Education Reform (EER) [8], [9]. However, there is currently no systematic literature review (SLR) on "Emerging Engineering Education" in the Web of Science (WOS) database. Focusing on EEE, our SLR aims to analyze the trends of EER, reveal the current situation of EEE development in China, and provide useful insights for guiding future research. This SLR will address the following three research questions:

RQ1: What are the current research trends based on existing literature on China's EEE?
RQ2: What is the current development status of China's EEE?
RQ3: What are the future research directions of China's EEE?

2 METHODOLOGY

It is worth noting that the terms "Emerging Engineering Education" (EEE) and "New Engineering Education" (NEE) translations are both used in international literature. To ensure consistency throughout this paper, the discussion in this chapter predominantly employs the term NEE as per the translation adopted in this study. Thus, both translations are utilized interchangeably to represent the meaning of the Chinese characters "新工科" (Chinese Pinyin: Xin Gong Ke). In summary, while EEE is predominantly adopted in this paper, the search process employed both NEE and EEE to obtain relevant literature.

Therefore, the SLR examines the WOS database for literature related to EEE, NEE, and education. Specific methodological details for this review are outlined below.

2.1 Database sources

The review of relevant literature was conducted through a search of the WOS databases. This database platform was chosen for conducting the SLR on EEE due to its comprehensive coverage and high-quality indexing of academic journals. Renowned for its rigorous selection criteria, WOS ensures that the included journals meet the highest scholarly standards. Additionally, it offers extensive citation information and robust search functionality, enabling researchers to effectively trace the impacts and development of research trends. Moreover, due to its interdisciplinary nature, WOS provides a broad perspective, which is essential for capturing the multifaceted nature of EEE. Compared to other databases, the emphasis of WOS on high-impact publications and its extensive citation network make it a superior choice for conducting a thorough and reliable literature review.

2.2 Inclusion and exclusion criteria

First, researchers entered the following search query: (ALL = ("new engineering education") OR ALL = ("emerging engineering education")) AND (ALL = (China)) (see Figure 1). Next, we selected articles from 2017 to 2024. Subsequently, we excluded the conference papers and other materials, retaining only journal articles. Finally, the researchers reviewed the title, abstract, and content of the selected articles, removing those that were not relevant to the topic.

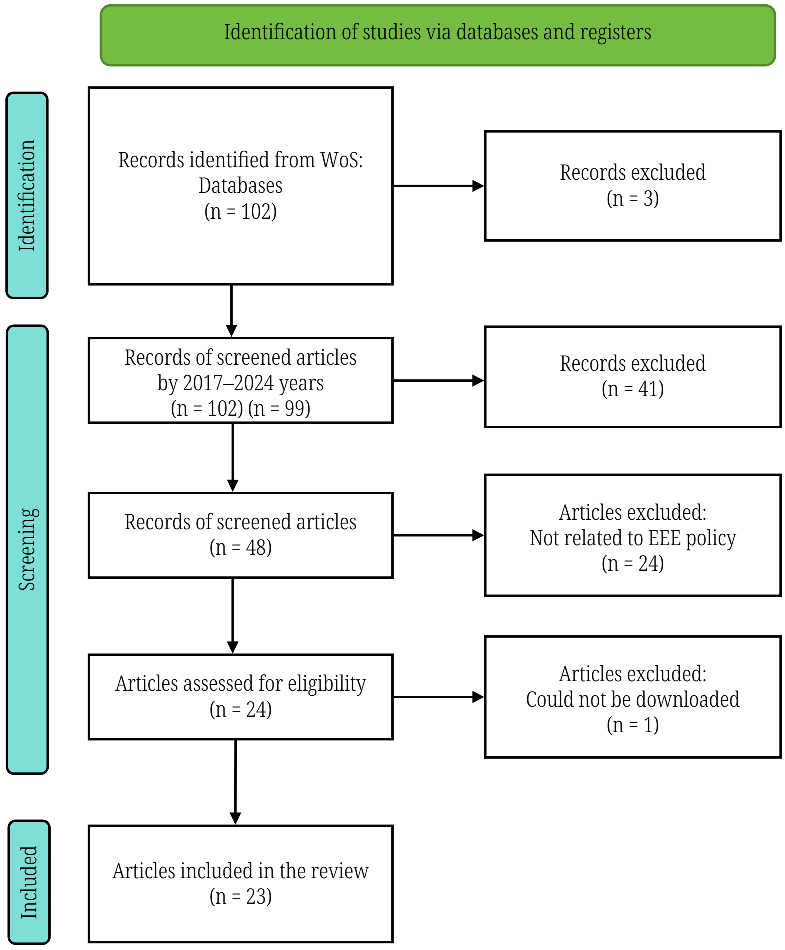

Fig. 1. Identification of studies via databases and registers (data up to May, 2024) [25]

3 RQ1: AN OVERVIEW OF CURRENT RESEARCH BASED ON EXISTING LITERATURE

The study examined the publication trends in the field of EEE and NEE between 2017 and 2024 (refer Table 1). Findings revealed that the study field achieved a peak of approximately six publications per year between 2020 and 2021. However, after 2022, the number of publications began to decline. This trend implies that, while research in the field has been active in recent years, interest has waned, indicating a shift in research focus and academic interest, or a decrease in research resources in this field.

Table 1. The trend of publication in the study field

Year	Number of Articles
2023	4
2022	5
2021	4
2020	5
2019	3
2018	1

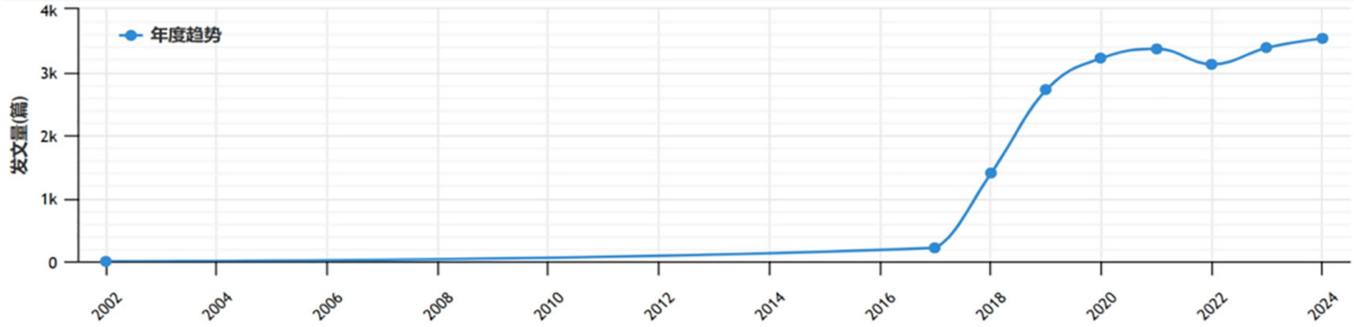

Fig. 2. Trend of publications on 'EEE' in Chinese journals

Since 2017, the number of research papers on EEE in Chinese journals has shown a continuous upward trend. However, by 2022, this rapid growth began to decelerate, and by 2023, the publication rate returned to a steady growth state.

The number of authors involved in publications on the topic of EEE and NEE has also increased. Although the authors' countries of origin were unknown, we examined their institutional affiliations to study the collaboration between the authors (refer Table 2). This data highlights Chinese scholars' participation in international academic cooperation. Notably, 13 papers (56%) were authored by scholars from China, indicating that Chinese scholars have a significant presence and influence in EEE and NEE research. In addition, collaboration with scholars from England and Australia represents five (21%) and three (13%) papers, respectively, revealing that Chinese scholars are actively collaborating with researchers from these countries (see Figure 2). The current body of literature on EEE is dominated by authors linked with academic institutions, with a conspicuous lack of contributions from industrial professionals and engineers. Due to this issue, current research lacks the valuable perspective of individuals directly involved in the practical application and advancement of engineering practices. Consequently, the ideas and findings from these studies may be constrained to only the academic perspective, emphasizing the importance of increasing engagement with industry professionals in order to enhance the discourse by incorporating practical, real-world experiences while addressing industry-specific issues.

Table 2. Authors' collaboration

The Country of Authors' Institutions	Number of Authors' Collaboration
China	13
China and Australia	3
China and Portugal	1
China, England, and New Zealand	2
China, England, Australia, and Singapore	1
China and USA	1
China and England	2

RQ1-Theme 1: The institutionalization of Emerging Engineering Education Research (EEER) in China

Research trends in EEE cover a broad range of areas influencing the field. One significant trend is the institutionalization of EER in China, specifically within the context of EEE. This involves defining research agendas that focus on epistemologies, learning mechanisms, institutional environments, diversity, inclusiveness, and assessment [4]. EER has evolved into a distinct field, characterized by a second-order region that integrates various research traditions and embraces methodological diversity [4]. The criteria for quality scholarship in engineering education encompass a range of elements, including research questions, theory, data, methodologies, findings, and international interdisciplinary concerns, indicating a push towards high-quality scholarship in China [4]. Key aspects include: (1) diversified ways of institutionalizing China's EER in response to the nation's developmental and societal needs, demonstrating growing interests and recognition in EER; (2) the need to develop EER graduate programs that are deeply influenced by the education discipline; (3) scholars from diverse backgrounds who engage and contribute to EER; and (4) research conducted at various levels (micro, meso, and macro) that complement, inform, and shape the Chinese research agenda.

RQ1-Themes 2: The development of innovative models for engineering talent cultivation

Additionally, the development of innovative models and practices for engineering and technology talent cultivation is another key focus in this study. This includes the establishment of new engineering programs, such as artificial intelligence (AI) and robotics, which emphasize different knowledge structures, instructional methods, and outcomes compared to traditional programs [4], [10]. Additionally, the integration of digital education and big data analytics courses has contributed to enhancing the skills and employability of engineering students, highlighting the role of digitalization in education [11]. Sustainability has been incorporated into engineering curricula under the "EEE" framework, emphasizing formal teaching approaches [9].

The reviewed articles primarily focus on outcome-based education (OBE), which has the potential to significantly improve classroom instruction and address the need for high-quality talent in modern engineering education. OBE focuses on learning objectives and skill development, which, for instance, may include a "short-term experimental project on engineering challenges" that employs finite element analysis (FEA).

Furthermore, there is a shift towards OBE to enhance classroom teaching quality, as evidenced by projects involving methods such as finite-element experiments for undergraduate students [12]. The exploration of data mining techniques and machine learning algorithms in multimedia systems aims to boost employment prospects and educational development. Virtual simulation teaching platforms have been innovatively applied to enhance remote sensing education, focusing on system design, teaching strategies, and experimental methods [8].

4 THE CURRENT DEVELOPMENT STATUS OF CHINA'S EMERGING ENGINEERING EDUCATION

The previous section primarily discussed the analysis of publication trends based on the collected literature, highlighting the evolution of research in EEE over time. In contrast, this section focuses on specific aspects related to EEE, addressing the challenges, issues, and development trends identified in the literature. By shifting the focus from generic publishing metrics to the substantive aspects of emerging engineering, we aim to gain a deeper understanding of the key areas that require attention and provide inputs for future directions in advancing this study field.

Several key themes emerged from this research in order to synthesize the findings of the 23 reviewed articles. In general, the studies delved into various aspects of engineering education, which include innovative teaching approaches, evaluation frameworks, interdisciplinary approaches, and the integration of emerging technologies. One prevalent theme is the emphasis on evaluation frameworks to assess stakeholder capacity, student perceptions, and teamwork competence [13], which aimed to enhance curriculum effectiveness and student learning outcomes. Another study highlighted the importance of systematic and long-term evaluation data acquisition for effective assessment in engineering education [14]. In terms of teaching methodologies, there is a focus on blended teaching approaches that combine traditional classroom learning with online components to cater to diverse student needs and improve learning outcomes [14]. Other studies explored the integration of digital education, big data analytics, and sustainability into engineering curricula to enhance students' skills and employability [9], [13]. Furthermore, another study underscored the significance of EER in different contexts, such as China and the United States, emphasizing the development of theoretical frameworks, research agendas, and the legitimization of EER as a field [4]. The scholars also discussed the evolution of EER from curriculum reformation to fundamental research on student learning in engineering [4]. Several studies addressed the cultivation of engineering and technology talent through innovative models, practical teaching approaches, and the incorporation of entrepreneurship education [10], [15], [16]. The scholars also explored the impacts of new engineering education paradigms, including EEE in China, which focuses on interdisciplinary courses, innovation, and global perspectives [10], [17]. Overall, findings from the 23 articles collectively contribute to advancing knowledge in engineering education by exploring diverse teaching strategies, evaluation methods, research agendas, and the integration of emerging trends to enhance the quality and relevance of engineering curricula. Additionally, OBE has been reported as effective in improving the quality of classroom teaching. Specifically, experimental projects focused on OBE can improve students' engineering practice abilities and yield satisfactory teaching results [12].

4.1 The development of the EEE policy

Public concern in China has been focused on improving EEE in order to increase the nation's competitiveness [12]. EEE is a diverse field that encompasses various aspects of innovation and reform in teaching methodologies, curriculum design, and talent cultivation. Several articles provide insights into different dimensions of this evolving landscape. One key aspect highlighted in the literature is the shift towards new educational concepts and models in engineering education [13]. This includes the development of innovative teaching approaches, such as flipped classrooms and virtual simulation platforms, aiming to enhance practical abilities and provide students with hands-on experiences [8], [18]. Additionally, there is an emphasis on integrating emerging technologies, such as Building Information Modeling (BIM), into engineering curricula to improve performance and efficiency in areas such as highway engineering [13], [15]. Moreover, the importance of OBE and the conception-design-implementation-operate (CDIO) model in talent training were also highlighted [15]. These models aim to foster a holistic approach to education that considers general, professional, and innovative aspects of engineering training. Furthermore, the integration of sustainability principles into engineering curricula has been highlighted as a crucial component of the EEE paradigm [9]. The literature also discussed the global context of EER, with a particular focus on China's institutionalization of EER under the EEE initiative [4]. This initiative has led to the establishment of research agendas and academic infrastructures that are grounded in Chinese history and culture, influencing the direction and diversity of EER in the country. In conclusion, the EEE landscape is characterized by a shift towards innovative teaching practices, the integration of new technologies, a focus on outcome-based and sustainable education models, and the institutionalization of EER in response to global and national initiatives.

With the rapid expansion of China's economy and society, there is a growing demand for high-quality engineering graduates. The NEE strategy has emerged with the aim to improve the quality of engineering education and its global competitiveness. The primary goal of this strategy is to cultivate an engineering education environment that meets international standards, emphasizing the combination of classroom learning and the transfer of social knowledge in order to enhance the overall development of talent.

In China, core theoretical courses of higher education engineering curriculum are generally delivered in the first two years, followed by more specialized courses in the third and fourth years. Freshman and sophomore students often dedicate a significant amount of time adjusting to the learning environment and studying theories, compared to junior and senior students who focus on graduation projects and internships. The new engineering course is viewed as a thorough reform of engineering education in China's higher education system, featuring a strategic plan aimed at developing engineering talent over the next decade. This reform builds upon the 2017 Fudan Consensus, Tianda Action, and Beijing Guidelines, with the goal of achieving international accrediting standards that are consistent with the certification criteria of the Washington Accord [19]. The implementation of the NEE plan is inextricably linked to China's competitiveness in the age of Industry 4.0. However, insufficient attention is currently devoted to the enhancement, application, and transfer of knowledge in society, as well as the promotion of the technology transfer cycle. As a result, China's Ministry of Education is committed to increasing the quality of teaching and learning to better align with the evolving market needs.

4.2 Practice teaching

In the realm of EEE policies, discussions surrounding teaching methodologies have been a central focus in scholarly articles. The literature emphasizes the need for innovative teaching approaches that are in line with the evolving engineering landscape [14], [15], [20]. There is an emphasis on the importance of integrating various teaching approaches, incorporating virtual reality (VR) applications, and implementing practical teaching reforms to enrich students' learning experiences [20]. The development of EEE policy necessitates a comprehensive approach to integrating practical engineering applications into educational curricula. FEA plays a crucial role in enhancing students' understanding of theoretical mechanics and computational methods [12]. By implementing OBE models, educational institutions can bridge the gap between theoretical knowledge and practical skills, thereby improving the quality of engineering education [13], [15].

These strategies aim at amalgamating theoretical knowledge with practical skills, thereby equipping students to address real-world engineering challenges.

Furthermore, one of the articles highlighted the critical role of evaluation frameworks in gauging the effectiveness of practice teaching within engineering education [13], delving into evaluation models such as Brinkerhoff's Six-Stage Model and Stufflebeam's CIPP model to assess the impact of educational inputs on learning outcomes. By scrutinizing the entire process from implementation strategies to learning outcomes, educators can fine-tune their teaching methodologies and enhance the quality of engineering education [13], [20]. Moreover, the literature underscored the significance of interdisciplinary approaches in engineering education, advocating for collaborative learning environments where students from diverse backgrounds work together on projects, fostering interdisciplinary thinking and enhancing problem-solving skills. This collaborative approach aligns with the demands of the contemporary engineering industry, which necessitates professionals with a diverse skill set capable of functioning effectively across multiple disciplines.

There are notable distinctions between the roles and qualities of practical and theoretical teaching within the educational process. Practical instruction typically involves a longer cycle and greater continuity, enabling it to complete tasks in a more flexible time frame rather than involving only a few classes [21]. In recent years, the education sector has increasingly adopted a multidisciplinary cooperation approach to enhance the integration of practical and theoretical training. This strategy, which involves teachers, government, businesses, and research institutions, strives to build a collaborative educational platform. Consequently, innovation and entrepreneurship courses have been effectively incorporated into professional programs [22]. Furthermore, the development of smart teaching technologies, such as pinning and micro-assistants, has significantly improved interactive learning in classrooms. These technologies improve communication between professors and students, allowing students to engage more actively in the learning process [23].

4.3 Challenges and issues

Engineering education faces several challenges and issues. One of the key challenges is the need for innovative models and practices to cultivate engineering and technology talent [10]. This challenge is exacerbated by the fact that some students lack a clear understanding of engineering and the necessary basic knowledge for pursuing an engineering degree [10]. Most of the present teaching methods also lack a solid engineering background [12].

Additionally, there is an increasing emphasis on the importance of self-motivation, autonomy, and academic self-awareness among students, as these factors can significantly impact their transformation and success in engineering education [10]. Institutionalizing EER is another critical aspect that presents challenges. In China, EER is evolving as a sub-discipline within higher education, drawing on educational and learning theories from social sciences while aligning with engineering practices and educational policies [4]. The need to establish EER as a Community of Practice (CoP) highlights the importance of integrating knowledge and expertise from various fields, including engineering, education, and social sciences, into EER [4]. Moreover, the legitimacy and conceptualization of EER as a distinct field are subjects of discussion among engineering education scholars [4]. The rapid development of emerging engineering programs, such as AI and robotics, presents another challenge. These programs require different knowledge structures, instructional methods, and outcomes compared to traditional engineering curricula, highlighting the need for establishing collaboration between educators and academics to design effective curricula [4]. Furthermore, successful integration of sustainability into engineering curricula within the EEE framework requires formal and diverse teaching approaches [9]. Overall, the challenges and issues in engineering education encompass the need for innovative models for talent cultivation, addressing students' understanding and motivation, institutionalizing EER, adapting to the demands of EEE, and integrating sustainability into curricula. These challenges highlight the evolving nature of engineering education and the importance of continuous adaptation to meet the demands of both students and the industry.

5 FUTURE RESEARCH DIRECTIONS

Future research directions in EER should focus on addressing various challenges while advancing the field towards more rigorous and impactful outcomes. One key aspect is the institutionalization of EER, which requires defining a well-structured research agenda that focuses on epistemologies, learning mechanisms, institutional environments, diversity, inclusiveness, and assessment [4]. This entails transitioning from fragmented interests to a more disciplined approach that integrates theoretical frameworks and research methods [4]. Additionally, there is a need to establish collaborative networks and global dialogues among EER scholars and practitioners to promote knowledge sharing and research capacity building [4].

Furthermore, future research should aim to bridge the gap between theoretical research and practical applications in engineering education. This involves conducting fundamental research on student learning in engineering while also focusing on curriculum and instruction reformation [4]. Embracing innovative models and practices, such as VR technology, data mining techniques, and machine learning algorithms, can enhance teaching effectiveness and student engagement. Moreover, integrating digital education, big data analytics, and sustainability principles into the engineering curriculum can improve students' skills and employability [9], [10], [11], [16]. Another critical area for future research is the evaluation of educational interventions and programs. Developing robust evaluation frameworks, such as the CIPP model, can facilitate the assessment of the effectiveness of teaching methods, learning outcomes, and educational practices [24].

In conclusion, future research directions in EER should focus on enhancing research rigor, promoting collaboration and knowledge sharing, integrating innovative technologies, bridging the gap between theory and practice, and evaluating the impact of educational interventions. By addressing the aforementioned challenges and advancing these research directions, the field of EER can continue to evolve and make substantial contributions to the enhancement of engineering education on a global scale.

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