How Entrepreneurship Enhances the Development of the Chemical Engineering Industry: A Review Insight for

Future Research and Industry Application

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**Abstract.** Entrepreneurship plays a vital role in the evolution and application of the chemical engineering industry. This review aims to determine the status of the development of literature studies related to the role, challenges, and keywords that enhance the development of the chemical engineering industry for future research opportunities and industry application. Following the PRISMA protocol, a systematic literature review was conducted, sourcing data exclusively from Scopus. Findings reveal three primary roles of entrepreneurship to enhance the development of the chemical engineering industry: enhancing creativity and entrepreneurial attitude, facilitating commercialization and sustainable development, and encouraging collaboration and competence development. Research findings indicate that entrepreneurship drives the development of sustainable solutions and efficient commercialization processes, which are critical for meeting the industry's evolving demands. Additionally, three primary challenges were identified: technology readiness, conservatism barriers, and the expected skills gap between academic training and industry requirements. The value of this research lies in its comprehensive overview of the interconnected dynamics of entrepreneurship and the chemical engineering industry. The study proposes that addressing these roles and challenges through collaborative efforts among educational institutions, industry leaders, and policymakers is essential for nurturing an ecosystem conducive to innovation and technological progression in chemical engineering. Therefore, this paper concludes that creating an ecosystem that supports innovation and technological progression in chemical engineering is necessary, whereby educational institutions, industrial leadership, and policy leaders overcome these roles and challenges.

**Keywords:** Chemical Engineering, Chemistry, Entrepreneur, Entrepreneurship, Systematic Literature Review.

# INTRODUCTION

Entrepreneurship is increasingly part of the projects related to the chemical engineering industry in many countries worldwide, and entrepreneurship plays a vital role in driving progress in this sector. Entrepreneurship generally integrates various environmental, social, and economic indicators to develop aptitudes and abilities through the chemical engineering industry [1]. The entrepreneurial attitude has posed innovative processes, materials, and technologies that have transformed the field of chemical engineering [2]**.** Thus, entrepreneurship's integration into chemical engineering expanded interdisciplinary work and contributed to sustainable solutions towards complex, social, and environmental problems [3].

The chemical engineering industry and entrepreneurship are interconnected due to their shared emphasis on innovation and problem-solving. Chemical engineering challenges involve those related to sustainable manufacturing, waste management, and renewable energy [4]. Entrepreneurship takes these solutions and helps to translate them into commercially viable products or services [5]. This correlation further helps the economy and applies to scientific developments in real life. By combining technical expertise with entrepreneurial strategies, chemical engineers are better equipped to meet evolving market demands [6]. On the other hand, they can also tackle global challenges and contribute to the development of the entire industry. This dual focus makes it critical to

explore how entrepreneurship enhances the development of the chemical engineering industry. So, it can offer insights into future research and industry applications.

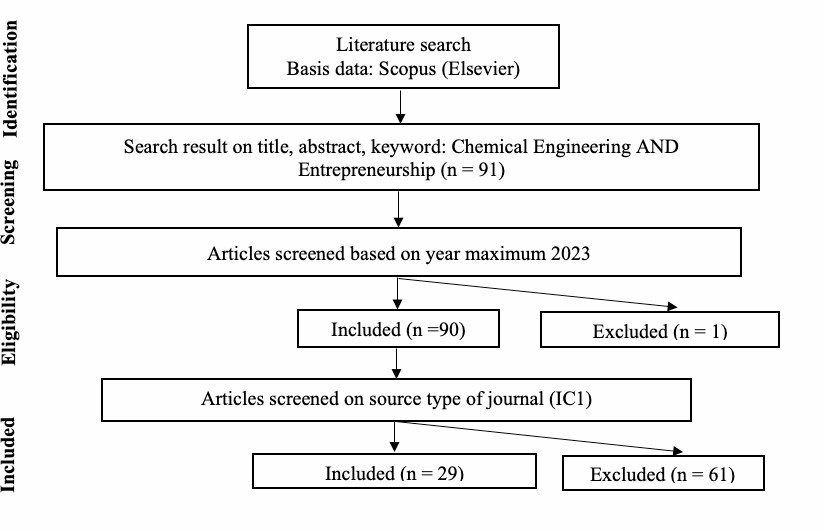
Given this development, an important question is whether entrepreneurship is necessary for chemical engineering to adapt to the swiftly evolving market demands and technological progress. Therefore, studies on entrepreneurship in chemical engineering provide divergent views on its potential to improve this industry. Entrepreneurship encourages chemical engineers to be more proactive in problem-solving by thinking critically from a creative and strategic point of view [6]**.** Entrepreneurship allows chemical engineers to use their technologically acquired expertise in an area where an opportunity for commercialization might lie. Then, they can translate a very innovative idea into the most commercially decent new product [7]**.** This pro-activeness does not directly impact economic growth within the chemical engineering industry; instead, it adds to the competitiveness of the sector internationally [8]**.**

The systematic literature review (SLR) methodology is often used because it offers distinct prospects for advancing research in business-based chemical engineering. SLR was advanced in response to the more excellent reflection and integration within entrepreneurship research, as criticized for providing fragmented evidence from a broad disciplinary base. By systematically synthesizing and identifying the gaps in the existing knowledge of entrepreneurship in specific fields, SLRs will have a significant impact by providing valuable insights into the current entrepreneurship landscape in chemical engineering [9], [10]. This methodology can pick up trends, patterns, and best practices to derive future research and application directions from the field [11]. Therefore, SLRs are a comprehensive and unbiased window for the analysis of chemical engineering entrepreneurship; hence, any research findings are evidence-based [12]**.**

Previous research about entrepreneurship in chemical engineering has highlighted various aspects that ensure further investigation through a systematic literature review (SLR). Many analyses of the selected study show that entrepreneurship in chemical engineering has explored the impact of personal characteristics, such as the need for achievement, locus of control, risk-taking tendency, and creativity, on entrepreneurial purposes among engineering students [13]. The existing studies have demonstrated the advantage of entrepreneurship education for engineering students in encouraging innovative thinking in business ventures [14] [15] [16]. However, it is necessary to fill in the gaps in how entrepreneurship skills influence project performance within the chemical engineering industry, indicating the need for more research in this area. This review aims to determine the status of the development of literature studies related to the role, challenges, and keywords that enhance the development of the chemical engineering industry for future research opportunities and industry application.

# METHODS

In this work, a Systematic Literature Review (SLR) has been carried out following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) protocol, as seen in Figure 1. The PRISMA source is chosen to be followed as it is performed within a rigorous framework, ensuring a transparent, systematic review [17], [18]. It also requires guidelines for selecting, eligibility, and exclusion articles, which should provide a full- scale covering of the relevant literature concerning the purpose of the research that is crucial for synthesizing evidence effectively [19]. The study collected data from the Scopus Database, which holds chemical engineering and entrepreneurship data [20]. The coverage of Scopus is of high quality and is broad, further holding relevance for this review.



**FIGURE 1.** PRISMA Protocols

The search command keywords in the document search have been "chemical engineering" and "entrepreneurship", combined with the corresponding terms. Twenty-nine documents were reviewed and met the inclusion criteria for chemical engineering and entrepreneurship, publications in journals, and articles up to 2023, as seen in Table 1. The search query option used in data mining was as follows ( TITLE-ABS-KEY "chemical engineer\*" AND TITLE-ABS-KEY (entrepreneur\*)) AND PUBYEAR > 1971 AND PUBYEAR < 2024 AND (LIMIT-TO (SRCTYPE , "j") as of May 2024.

**TABLE 1.** Inclusion Criteria

**Inclusion Criteria Description**

Topics Address chemical engineering and entrepreneurship Publication Source Published in a scholarly journal at Scopus Database Publication Year Published up to the year 2023

The research questions (RQs) guiding the study were structured as follows.

* *RQ1: What are the roles of entrepreneurship in enhancing the development of the chemical engineering industry?*
* *RQ2: What are the challenges of implementing entrepreneurship to enhance the development of the chemical engineering industry?*
* *RQ3: What are the word clouds for entrepreneurship studies in the chemical engineering industry?*
* *RQ4: What are the future research studies in entrepreneurship that will enhance the development of the chemical engineering industry?*

For the analysis, RQ1 and RQ2 have been analyzed descriptively and thematically using the Gioia method, which offers a structured approach to analyzing qualitative data, enabling a deeper understanding of the roles and challenges identified of entrepreneurship to enhance the development of the chemical engineering industry. The Gioia method provides a systematic framework for organizing and interpreting textual data, facilitating the extracting of meaningful insights from the literature [21]. RQ3 has been bibliometrically analyzed using the R Biblioshiny tool, which allows for the visualization and quantitative analysis of bibliographic data, aiding in identifying patterns of word cloud in the literature [9]. Finally, RQ4 has been analyzed descriptively to explore and outline future research directions in entrepreneurship studies within the chemical engineering industry.

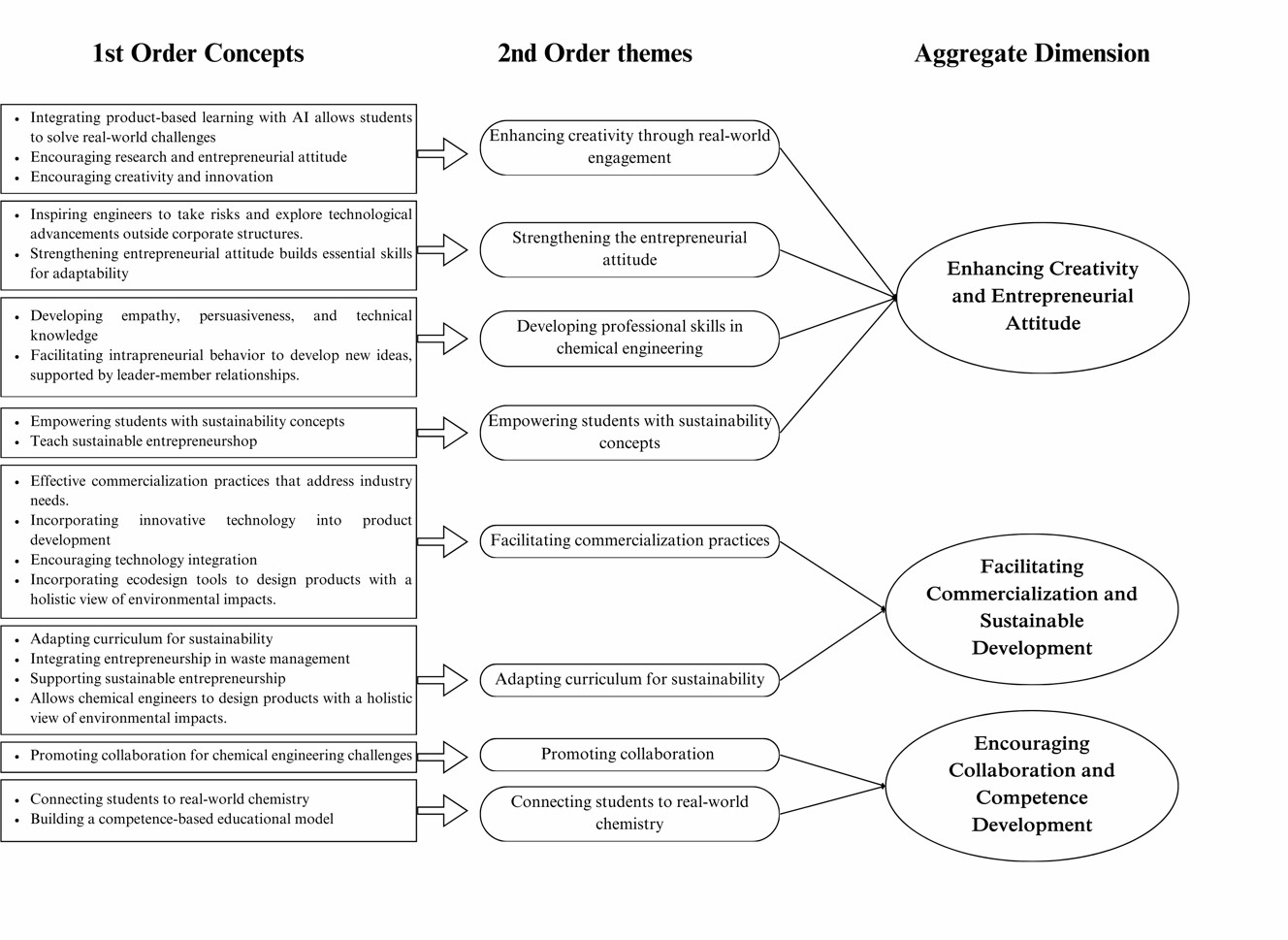
# RESULTS AND DISCUSSION

## The Roles of Entrepreneurship in the Chemical Engineering Industry

Figure 2. below is a visual exposition in which entrepreneurship implementation roles within the chemical engineering industry can enhance creativity, nurture an entrepreneurial mindset, facilitate commercialization and sustainable development, and bolster collaboration and competence development. The role of entrepreneurship in enhancing the development of the chemical engineering industry is summarized in a detailed analysis of the composite dimensions in Fig 2.

### Aggregate Dimension: Enhancing Creativity and Entrepreneurial Attitude

As shown in Figure 2, entrepreneurship in the chemical engineering industry can enhance creativity through real- world engagement. In this sense, this approach allows students to actively make them get in touch with raw materials by solving real problems that can stimulate their creativity and boost their entrepreneurial skills [22]. This creativity was mainly due to integrating product-based learning with AI, encouraging research and an entrepreneurial mindset [23], and inspiring creativity and innovation [24], [25]. In addition, entrepreneurship can inculcate an entrepreneurial attitude [26] since it encourages the engineer to take risks, explore outside corporate structures, and attain skills for being adaptable [27]. On the other hand, it integrates professional skills development under the chemical engineering discipline. These include empathy, persuasiveness, technical knowledge, and intrapreneurial behavior toward innovation and new ideas [28].



**FIGURE 2**. The Role of Entrepreneurship in the Chemical Engineering Industry

### Aggregate Dimension: Facilitating Commercialization and Sustainable Development

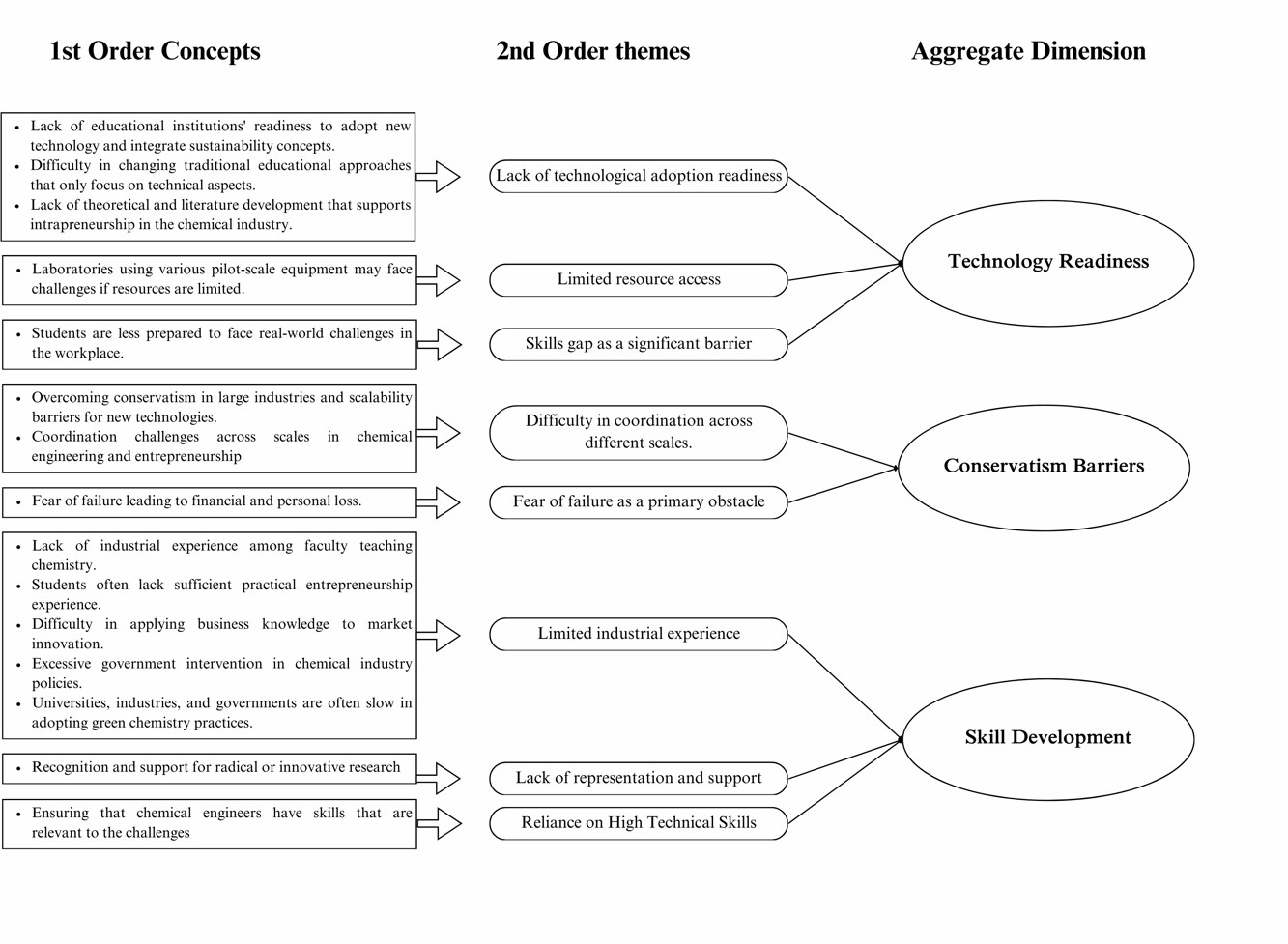
Through education, which is more focused on real applications in industry, chemistry students are taught to understand the theory and the theoretical application of their knowledge [29]. Thus, entrepreneurship can make commercialization practices easy. These include commercial practices that are effective [30], implementation of any industry needs [31] by incorporating innovative technology into product development, encompassing ground- breaking technology, and product designs that should be done while considering the impact on the environment from a holistic point of view [32]. The role of entrepreneurship in chemical engineering has been used as a sustainability concept for individual students. For instance, entrepreneurship, as indicated in Figure 1, has the potential to teach the concept of sustainable entrepreneurship and the aspects of the curriculum that can be changed to instill sustainability under various chemical engineering applications [33]. Moreover, waste management constitutes part of the works of chemical engineering about coming up with sustainable ways and ideas that limit waste, which is quite resourceful in the context of sustainable entrepreneurship [34], [35], along with the holistic view to create sustainable products.

### Aggregate Dimension: Encouraging Collaboration and Competence Development

It encompasses the social aspect of the chemical engineering arena, and in bringing forth collaboration, two essential things were enhanced. Building synergy between the students and real-world chemical problems in developing competence will give them real-world experience in product development, manufacturing, and marketing; this is especially valuable for aspiring entrepreneurs [36]. The second enhancement was to connect the students with real- world chemistry, such as building up the competence-based model of education concerning industry requirements that will promote real-world chemical education [37]. All these dimensions together intend to develop well-rounded, innovative, and collaborative chemical engineers who can overcome challenges coming their way, promising an ecosystem in which education directly contributes towards industry and sustainable development [35].

## The Challenges of Implementing Entrepreneurship in the Chemical Engineering Industry

The data structuring and analysis process with the Gioia thematic method then obtained three-dimensional aggregates developed to describe the challenges faced when implementing entrepreneurship in the chemical engineering industry, as shown in Figure 3. These aggregate challenges are technology readiness, conservatism barriers, and skill development. Each of these dimension aggregates is described in the following sections.



**FIGURE 3**. The Challenges of Implementing Entrepreneurship in the Chemical Engineering Industry

### Aggregate Dimension: Technology Readiness

In this work, the finding discloses the implication that the business-based chemical engineering industry might face some challenges. There is difficulty in mainstreaming entrepreneurial principles into traditional education, which focuses more on technical facets [28]. The lack of technological adoption readiness could hinder the adoption of entrepreneurship curricula in the chemical engineering industry [38]. Moreover, there is a deficiency of theoretical frameworks and literature that supports intrapreneurship in the chemical industry [39]. Next to limited resource access [35], some agencies should be facing negotiation processes such as securing funding for new, commercially unproven technologies is a significant challenge. Controversy and uncertainty often make investors or government agencies hesitant to fund projects [40]. Laboratories frequently utilize various pilot-scale equipment, but the lack of guaranteed funding can hinder progress and innovation. One of the main challenges that also might appear is the skills gap between what is taught in educational institutions and what is required by industry [41], [42].

### Aggregate Dimension: Conservatism Barriers

In the second stage, the conservative barrier was identified as one of the difficulties. One of the most significant barriers is the existence of institutional and cognitive inertia in universities, industry, and government, which constrains the introduction of more sustainable green chemistry practices. Institutions typically have an unwelcome tendency to remain on the old track, either because of cost, tradition, or due to existing regulatory arrangements [43]. Therefore, coordination difficulty was included, too [44]. Chemical engineering comprises multiple scales – from molecular to global. Coordinating, when we talk in an entrepreneurial sense, is specifically challenging because, to start with, the time and space scales are different scales that should be overcome [39], [45]. Failure and

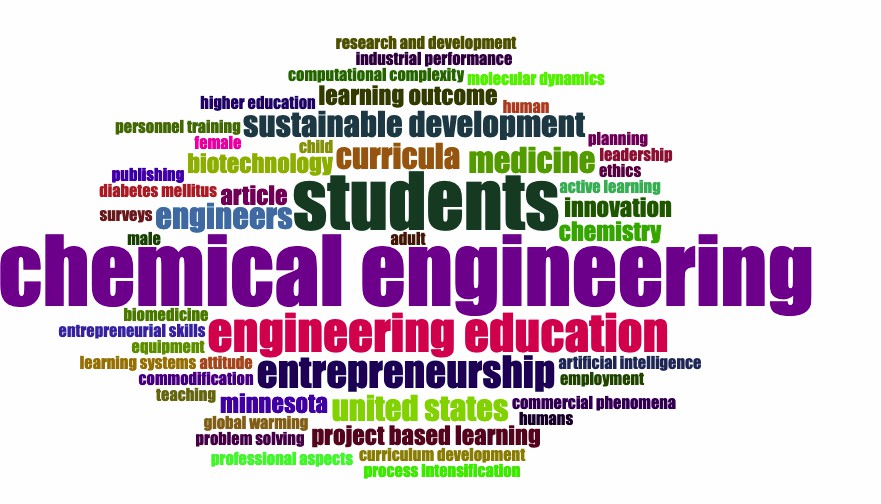
financial implications are also some of the main barriers for chemical engineers to move from stable employment to entrepreneurship [46].

### Aggregate Dimension: Skill Development

Regarding practical skills in the chemical engineering industry, students in the engineering field do not acquire practical experience that relates directly to the professional world, especially in entrepreneurship [37]. The fact that students engaged in chemical engineering often lack sufficient practical industry experience during their studies is owing to the lack of integration of business knowledge, which is necessary for the entrepreneurial development of practitioners in the industry [47]. Chemical engineering requires reasonably high levels of technical specificity, expertise, and competence that can serve as a barrier to more significant employment in the related industries in case of insufficient workers with such skills and competencies [48]. Besides, too many government intervention policies in the chemical industry can hinder creativity and responsiveness. The slow uptake of practices of green chemistry by universities, industries, and governments further hampers progress and sustainability [43]. During a polarizing debate, getting recognition and support for radical or innovative research is difficult, mainly if the approach is controversial to the broader scientific community [40]. Furthermore, low completion rates among minority students due to a lack of peer support and mentorship [30] and students' readiness to face unconventional coursework worsen these challenges [38].

## Word Cloud for Entrepreneurship Studies in the Chemical Engineering Industry

Figure 4 indicates the contributions of different keywords based on the number published in the discussion of entrepreneurship in the chemical engineering Industry.

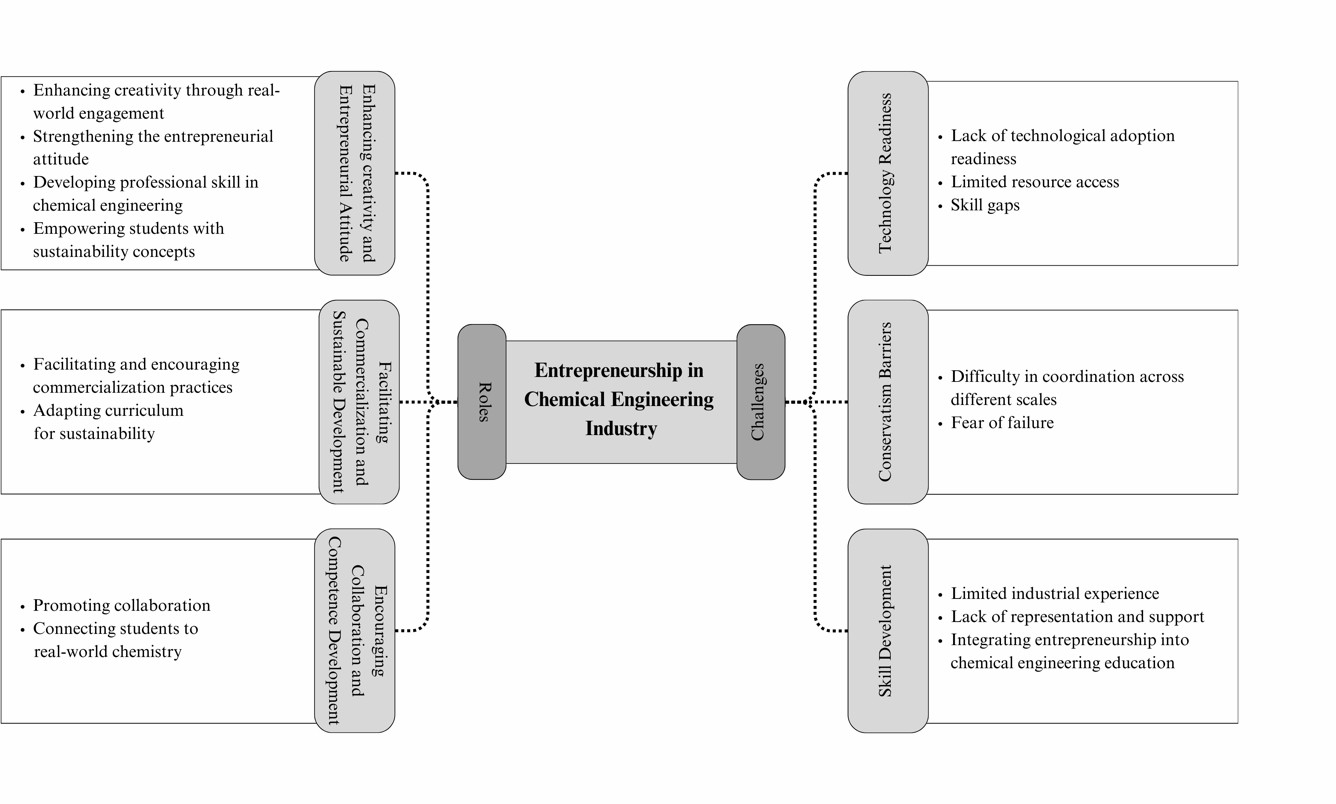


**FIGURE 4**. Word Cloud of Entrepreneurship in the Chemical Engineering Industry

The keywords "chemical engineering," "students," "engineering education," and "entrepreneurship" are among the most frequently appearing in the context of the research paradigm associated with entrepreneurship in chemical engineering, with the word "chemical engineering" having the highest contribution in this domain. It is considered closely interrelated in determining the educational environment of the future engineer. The fundamental importance of entrepreneurship within competencies improves the performance of projects and, therefore, the relevance of entrepreneurial competencies in engineering activities [49]. Moreover, it indicates the influence of entrepreneurial education on innovation capability by pointing out the fundamental importance of entrepreneurship in developing an innovative way of thinking among students [50]. In turn, the governance nexus between entrepreneurship and economic growth and, hence, the financial implications of entrepreneurial activities across contexts [51]. These sources have evidenced the multi-aspect interaction of chemical engineering, students, engineering education, and entrepreneurship, of which innovation, success in the projects, and economic development should be mentioned.

## Key Findings

The findings of this study show that entrepreneurship strongly influences creativity and embeds professionalism and sustainability concepts in the discipline of the chemical engineering industry. It empowers students and professionals with an entrepreneurial attitude by getting them deeply involved in real-world challenges that further fortify the former and develop the latter. This engagement then allows students to understand the concept of sustainability and prepares them for future challenges in the industry. The human aspect comes in through entrepreneurship, encourages creativity, and drives innovation in the chemical engineering field toward developing more sustainable and efficient processes.



**FIGURE 5**. The Roles and Challenges of Entrepreneurship in the Chemical Engineering Industry

Another vital area that entrepreneurship influences is commercialization and sustainable development in the chemical engineering industry. Modifying the curriculum towards sustainability and encouraging commercialization will enable the students to understand the gap between what is taught and how it is practiced in the industry. This link not only accelerates the commercialization of innovative solutions but also ensures that the nature of the solutions is sustainable. An entrepreneurship mindset developed in chemical engineering education places sustainability at its core, thus making sure there are long-term environmental and economic welfare contributions in the industry. Despite these positive impacts, several challenges have somehow hindered the successful integration of entrepreneurship within the chemical engineering industry. Technological readiness is hampered by the lack of resources on the one hand and a considerable skills gap on the other. There are also more conservative barriers, from the challenge to coordinate actions across scales to fear of failure, hampering entrepreneurial activity. Moreover, the lack of industrial experience and the absence of proper representation and support to integrate entrepreneurship within the core of chemical engineering education also hampers the development of relevant skills. These challenges must be met to harness entrepreneurship to its full potential in advancing the chemical engineering industry.

## Future Research in Entrepreneurship Studies in the Chemical Engineering Industry

This review shows a very high need for future research to understand the relationship between entrepreneurship and chemical engineering systematically. Issues that have emerged as needing further research include quantitative impact studies that directly measure the impact of entrepreneurial activity on industry performance indicators, rates of innovation, product development, and market success. Longitudinal studies of the long-term implications of entrepreneurial education on chemical engineering students in training that affect career development and industry performance need to be implemented. A unique critical nature needs to be paid through comparative, cross-cultural studies exploring the influence of different regulatory and economic environments on adopting entrepreneurial practices globally in the chemical engineering industry.

Future research will be able to clearly outline the pathways and difficulties involved in the adoption of technologies by start-ups and established firms in the chemical engineering sector. This should identify enabling factors or barriers to technology adoption and how these differ depending on the organizational context. Significant progress would be made by developing and testing strategies to overcome the identified obstacles of technology readiness, institutional conservatism, and skills shortage. Another exciting area of research is the interface between sustainability and entrepreneurship, demonstrating how new chemical engineering ventures can further sustainability objectives through green technologies, waste reduction, and resource-efficient ways. Future research will thus be better placed to serve these areas with more actionable insights and robust frameworks for enhancing innovation and sustainability in the chemical engineering industry.

# CONCLUSION

Availing mainstreaming entrepreneurship in the development of chemical engineering was done through a systematic literature review. Findings concluded that entrepreneurship has played a significant role in developing chemical engineering industries due to creativity and an entrepreneurial attitude, mainly while facilitating commercialization and sustainable development, which also encourages collaboration and competence development. Such capabilities are crucial to addressing effectively complex challenges faced by industry and the environment. There are, however, a few challenges to integrating entrepreneurship principles into the chemical engineering education and industry. Some prominent ones are readiness to adopt new technologies, conservative barriers inside the institutions, and skill gaps. The word cloud analysis identifies themes that dominate the literature and visually emphasizes critical educational and entrepreneurial components that could help improve the performance of the chemical engineering industry.

In light of the limitation of this study, it is essential to recognize that using the Scopus database may have constrained our findings. The result might be incomplete or missing emerging concepts based on the specific indexing criteria. From this point, academia, industry captains, and policymakers play a crucial role in enabling the birth of an innovation culture within the industry in handling these challenges. Reducing conservatism and eliminating the skills gap will significantly enlarge the operational effectiveness and adaptability of the chemical industry and practicing entrepreneurs. The government and policymakers must also encourage policies that deliver enhanced technology readiness, incorporating entrepreneurship training into the curriculum to ensure dynamism and responsiveness. Lastly, the results imply that entrepreneurship should be incorporated into the chemical engineering curriculum, a culture of innovation developed in businesses, and enabling policy frameworks so that the industries can compete and remain sustainable.

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