

# Technological Prospecction of Didactic Units in Chemical Engineering: patent trends and educational gaps

*Prospecção Tecnológica de Unidades Didáticas na Engenharia Química: tendências em patentes e lacunas educacionais*

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## Abstract

The lack of infrastructure in teaching laboratories at Brazilian public institutions compromises practical training in Chemical Engineering. This study conducted a scientific and technological prospecction of didactic units applied to teaching in this field, based on 30 publications indexed in Google Scholar, Scopus, and Web of Science (2009-2025), along with 3,840 patents retrieved from the Orbit database. In the scientific scope, only two specific initiatives focused on Chemical Engineering were identified. In the technological domain, China leads with 2,742 records, followed by India (133) and the United States (111). The active patents explore technologies such as Building Information Modeling (BIM), 3D simulations, and adaptive assessment. The results highlight significant gaps in the development of didactic solutions specific to the field, especially within public education. It is concluded that the integration of emerging technologies and open platforms represents a strategic opportunity for innovation in higher education in Chemical Engineering.

**Keywords:** Educational Intellectual Property; Emerging Technologies in Education; Didactic Infrastructure in Engineering.

## Resumo

A carência de infraestrutura em laboratórios didáticos nas instituições públicas brasileiras compromete a formação prática em Engenharia Química. Este estudo realizou uma prospecção científica e tecnológica sobre unidades didáticas aplicadas ao ensino da área, com base em 30 publicações indexadas no Google Acadêmico (2009-2025), Scopus e Web of Science, além de 3.840 patentes extraídas da base Orbit, das quais 2.986 estão ativas e 854 inativas. Apenas duas patentes específicas em Engenharia Química foram identificadas (uma ativa e uma inativa), e no âmbito científico, observou-se que apenas duas iniciativas estão diretamente voltadas para o tema. No cenário tecnológico, a China lidera com 2.742 registros, seguida pela Índia (133) e Estados Unidos (111). As patentes ativas abordam tecnologias como *Building Information Modeling* (BIM), simulações 3D e avaliação adaptativa. Os resultados evidenciam lacunas expressivas no desenvolvimento de soluções didáticas específicas para a área, sobretudo na educação pública. Conclui-se que a integração de tecnologias emergentes e plataformas abertas representa uma oportunidade estratégica para a inovação no ensino superior em Engenharia Química.

**Palavras-chave:** Propriedade Intelectual Educacional; Tecnologias Emergentes no Ensino; Infraestrutura Didática na Engenharia.

**Technological Areas:** Educational Technologies Applied to Engineering, Sustainable Engineering and Low-Cost Educational Infrastructure, Cyber-Physical Systems and Artificial Intelligence in Higher Education.



## 1 Introduction

Public higher education institutions have undergone significant transformations over the past two decades in response to national demands for professional training and the need to overcome infrastructure deficiencies. Decree No. 3,860 of July 9, 2001, which addressed the organization of higher education and the evaluation of courses and institutions, was repealed by Decree No. 5,773 of May 9, 2006, which regulated the functions of oversight, supervision, and evaluation of higher education institutions and programs within the federal education system. This decree was subsequently repealed by Decree No. 9,235 of December 15, 2017, which currently establishes the guidelines governing these functions in Brazilian federal higher education (Brazil, 2001; Brazil, 2006; Brazil, 2017). According to Decree No. 9,235 of December 15, 2017, existing and future laboratories, facilities, equipment, and technological resources must demonstrate their pedagogical relevance and alignment with the respective Program Pedagogical Project (PPC) (Brazil, 2017).

According to the 1988 Federal Constitution, particularly Article 213, item II, paragraph 2; Article 219, sole paragraph; and Article 219-B, as well as Law No. 10,973 of December 2, 2004, which establishes incentives for innovation and scientific and technological research, the State, through its agencies and public institutions, is responsible for promoting actions aimed at fostering scientific, technological, and innovative development (Brazil, 1988; Brazil, 2004).

Within this context, Law No. 11,892 of December 29, 2008, established the Federal Network of Professional, Scientific, and Technological Education and created the Federal Institutes of Education, Science, and Technology. Among the objectives of these institutions is the education, training, professional development, and continuous updating of professionals in various fields of professional and technological education, with particular emphasis on undergraduate technology programs, teacher education degrees, bachelor's degrees, engineering programs, and graduate studies at both the specialization and academic levels (Brazil, 2008). Considering Brazil's vast territorial dimensions, the creation of the Federal Institutes enabled the decentralization of quality public education, bringing educational infrastructure to regions that had previously been underserved. This public policy contributed significantly to democratizing access to higher education, particularly in the fields of science, technology, and innovation.

Law No. 13,243 of January 11, 2016, established measures to stimulate scientific development, research, scientific and technological training, and innovation. Article 19 stipulates that the Federal Government, states, the

Federal District, municipalities, Scientific, Technological, and Innovation Institutions (ICTs), and their funding agencies must promote and encourage research and the development of innovative products and processes through the provision of financial, human, material, or infrastructure resources. Such support must be formalized through specific instruments aligned with national industrial and technological policy priorities (Brazil, 2016).

Complementing this framework, Resolution No. 2 of April 24, 2019, issued by the National Council of Education and the Chamber of Higher Education (CNE/CES), established the National Curriculum Guidelines for Engineering Undergraduate Programs. These guidelines define a graduate profile characterized by strong technical training combined with a holistic, critical, reflective, collaborative, creative, ethical, and humanistic perspective. Graduates are expected to be capable of researching, developing, adapting, and applying new technologies while demonstrating innovative and entrepreneurial competencies. According to Article 6, item VIII, paragraphs 1 and 2 of the Resolution, laboratory activities are mandatory for the development of both general and specific competencies, with an intensity compatible with the specialization or emphasis of the engineering program. Furthermore, institutions are encouraged to promote activities that integrate theory, practice, and real-world applications, including extension initiatives and collaboration between academia and industry (Brazil, 2019).

Public higher education institutions, particularly state and federal universities, frequently face infrastructure deficiencies, especially regarding laboratories associated with engineering programs. These programs typically have extensive pedagogical curricula that combine common foundational disciplines with specialized courses designed to prepare students for highly technical professional activities. However, not all Brazilian institutions offering engineering degrees possess adequate infrastructure to support the practical activities required by these specialized disciplines. This limitation is particularly pronounced in institutions located in peripheral regions or far from major urban centers.

Engineering teaching laboratories require high-cost equipment, with acquisition expenses varying according to the specific program and technical requirements involved. In addition, qualified personnel are essential for operating such equipment, and technical support services are necessary to ensure proper maintenance and functionality.

Among the instruments commonly used in engineering laboratories are the Brookfield viscometer (ranging from approximately BRL 6,000 to BRL 25,000), laboratory calorimeters (between BRL 8,000 and BRL 50,000), and gas flow analyzers (ranging from BRL 15,000 to BRL 100,000). Although the market offers a wide variety of educational

devices, establishing a functional laboratory requires the integration of multiple pieces of equipment to enable the execution of experiments that are essential for students' technological training.

Therefore, the present study aims to contextualize the challenges faced by public higher education institutions regarding insufficient laboratory infrastructure in engineering programs. To achieve this objective, a bibliometric review of scientific and technological production related to the development of educational units applied to engineering laboratory contexts is conducted, with particular emphasis on low-cost solutions.

## 2 Methodology

This study adopts a qualitative and exploratory approach focused on the scientific and technological prospecting of documents related to the use of didactic units in Chemical Engineering education. To achieve this objective, two complementary information sources were employed: the Orbit Intelligence database, internationally recognized for the breadth and sophistication of its intellectual property analysis tools; and the Google Scholar, Web of Science, and Scopus databases, which are dedicated to scientific and academic literature.

The patent prospecting strategy was developed using Sofia, a native tool within the Orbit platform that enables the automated generation of structured search strings based on combinations of previously defined technical and thematic descriptors. The term *patent* was used in a broad sense, encompassing both patent applications and granted patents, regardless of their legal status. The retrieved patent documents were organized, analyzed, and classified according to criteria related to practical applicability, integration with educational technologies (including artificial intelligence, simulations, and computational modeling), and potential use in Chemical Engineering educational environments. In addition, aspects of incremental and radical innovation were evaluated, and the presence of solutions addressing sustainability and accessibility within educational contexts was identified.

For the scientific literature review, the Google Scholar search was restricted to scientific articles, undergraduate dissertations (final course projects), master's dissertations, and doctoral theses. The temporal scope began in 2009, immediately following the enactment of Law No. 11,892/2008, which established the Federal Institutes of Education, Science, and Technology (IFs). These institutions were created with the mission of promoting scientific and technological education through technical, technological, and higher education programs. No temporal restrictions were applied to searches conducted in the Web of Science and Scopus databases, as illustrated in Figure 1.

For the scientific prospecting component, searches were performed in Google Scholar, Web of Science, and Scopus using the following search string:

((“DIDACTIC UNIT” OR “TEACHING UNIT” OR “LEARNING UNIT”) AND (“CHEMICAL ENGINEERING”) AND (“TEACHING” OR “EDUCATION” OR “COURSE” OR “TRAINING” OR “HIGHER EDUCATION” OR “UNIVERSITY” OR “UNDERGRADUATE”))

For the technological prospecting component, the search was conducted using the Orbit Intelligence database, which is widely recognized for its extensive coverage and precision in intellectual property analysis. The search strategy was developed using the Sofia tool, which generates structured search strings based on predefined technical descriptors. The technological search string employed was as follows:

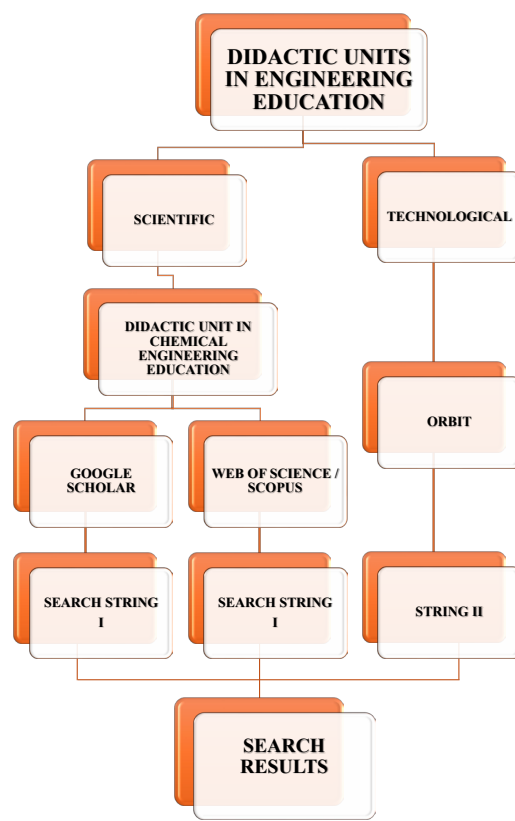
((DIDACTIC 3W UNIT) OR (DIDACTIC 3W MODULE) OR (TEACHING 3W UNIT) OR (EDUCATIONAL 3W MODULE) OR (INSTRUCTIONAL 3W UNIT) OR (LEARNING 3W MODULE) OR (TRAINING 3W MODULE) OR (COURSE 3W MATERIAL) OR (EDUCATIONAL 3W RESOURCE) OR (TEACHING 3W MATERIAL) OR (INSTRUCTIONAL 3W MATERIAL))/TI/AB/CLMS/SA AND (ENGINEERING OR (ENGINEERING 3W COURSE) OR (ENGINEERING 3W EDUCATION) OR (TECHNICAL 3W EDUCATION) OR (ENGINEERING 3W TRAINING) OR (ENGINEERING 3W CURRICULUM))/TI/AB/CLMS/SA AND (G09B OR G06F OR G16H)/IPC.

## 3 Results and Discussion

The chemical industry emerged from humanity's need to preserve and improve quality of life, initially through the empirical mastery of processes such as combustion, metallurgy, leather tanning, fermentation, and the production of natural medicines. However, it became established as a modern industrial sector only during the nineteenth century (Almeida & Pinto, 2011; Sapunaru & Macedo, 2016; Wongtschowski, 2002). Its development resulted from the integration of laboratory discoveries in Chemistry with industrial-scale production processes in Chemical Engineering, shaped by two major traditions: the German model, based on coal chemistry, and the American model, centered on petroleum chemistry and continuous production systems (Wongtschowski, 2002; Demajorovic, 2000).

The institutionalization of Chemical Engineering occurred in the early twentieth century with the establishment of the Chemical Engineering program at the Massachusetts Institute of Technology (MIT) in 1912.

**Figure 1** – Flowchart of the Scientific and Technological Search Strategy for Didactic Units in Engineering



Source: Prepared by the authors (2025)

This initiative helped define distinct methodologies and theoretical foundations for industrial development, while the United States assumed global leadership after World War II, driven by advances such as catalytic cracking and substantial investments in research and development (Wongtschowski, 2002; Demajorovic, 2000).

In Brazil, Engineering education formally began during the colonial period and expanded significantly throughout the twentieth century. A landmark development was the creation of the Aeronautics Institute of Technology (ITA) in 1950, recognized for its academic excellence and the introduction of an innovative pedagogical model for engineering education. This period also coincided with a substantial increase in engineering programs, particularly Chemical Engineering programs, whose expansion paralleled the establishment of strategic chemical industries and the broader development of the national industrial sector (Almeida & Pinto, 2011; Sapunaru & Macedo, 2016; Silva, Santos, & Afonso, 2006).

Automation and process control play a strategic role in Chemical Engineering by promoting efficiency, safety, and sustainability through the use of intelligent sensors, programmable logic controllers (PLCs), Supervisory Control and Data Acquisition (SCADA) systems, Artificial

Intelligence, and the Internet of Things. These technologies enable real-time monitoring and predictive failure analysis. In addition, technologies such as Digital Twins facilitate simulation, optimization, and loss reduction while integrating Industry 4.0 principles to address raw material variability, fluctuating market demands, and regulatory requirements. Consequently, the education of chemical engineers is increasingly aligned with the principles of clean, efficient, and resilient production systems (Sajadieh & Noh, 2025; Zhang et al., 2024; Min et al., 2019; Raven et al., 2024).

Despite these advances, Chemical Engineering education in Brazil continues to face significant structural limitations. Between 2007 and 2013, only 65.12% of federal universities partially achieved infrastructure-related goals, even though student enrollment increased from 140,000 to 243,000. This expansion was not accompanied by proportional investments in laboratories and essential infrastructure. The situation was further aggravated by budgetary constraints that resulted in a reduction of BRL 84.5 billion in funding, negatively affecting research grants and financial support mechanisms (Brazil, 2018; Paula & Martin, 2019). Such deficiencies compromise the development of competencies required to address

contemporary challenges involving process modeling, sustainability, renewable energy, and clean technologies (Arastoopour, 2019; INEP, 2017; Carvalho, 2023; Zhang et al., 2024).

Within this context, experimental didactic units, low-cost educational devices, and digital tools based on simulation and artificial intelligence have emerged as viable alternatives. At the same time, technological prospecting through patent analysis provides guidance regarding emerging trends and educational strategies aligned with the Brazilian reality, thereby strengthening innovation policies and scientific sovereignty (Paula & Martin, 2019).

The relevance of technological prospecting is demonstrated by the data presented in Table 1, which consolidates information obtained from four databases. In the Orbit database, 3,840 patent documents related to engineering education were identified, including 2,986 active and 854 inactive records.

Within the scientific domain, Google Scholar retrieved 18 publications, while Web of Science and Scopus each returned six records related to didactic units in Chemical Engineering.

These findings highlight the importance of using multiple search platforms to obtain a comprehensive understanding of scientific and technological trends related to the development of educational solutions. Among the active patents, applications of didactic units were identified across several engineering fields, including computer, civil, electrical, mechanical, aerospace, materials, petroleum, transportation, environmental, and safety engineering. However, only one active patent and one inactive patent were specifically directed toward Chemical Engineering, revealing a notable scarcity of structured technological solutions designed for this particular field.

Figure 2 presents the geographical distribution map of patent filings related to technologies designed for didactic units applied to engineering education, based on data extracted from the Orbit database. The blue color scale represents the number of patent records per country, while gray areas indicate the absence of identified records. China emerges as the leading patent applicant,

with up to 2,742 filings, highlighting its prominent role in technological innovation with potential applications in higher engineering education.

A significant geographical concentration of patent filings can be observed, reflecting asymmetries in the development and protection of educational innovations. India accounts for 133 patent records, followed by the United States with 111. In South America, Colombia leads with four patent filings, while Brazil records only two. The limited number of filings observed in Latin American countries may be associated with restricted investments in Research and Development (R&D), insufficient technological infrastructure, and the absence of robust policies encouraging intellectual property protection.

The geospatial analysis of patent filings constitutes a strategic tool for understanding global dynamics in educational innovation within engineering. Such analyses provide valuable insights for the formulation of public policies, the promotion of international collaborations, and the development of accessible and effective educational solutions capable of addressing contemporary challenges in engineering education.

In Figure 3(a), the organizations with the highest number of patent filings are predominantly Chinese institutions, with particular emphasis on universities and state-owned corporations such as the State Grid Corporation of China (SGCC) and Zhejiang University. This pattern suggests the existence of a robust national policy aimed at promoting intellectual property protection and the development of educational technologies. The geographical and institutional concentration of patent filings also indicates a possible strategic alignment among universities, government agencies, and the productive sector in China, thereby strengthening the technological innovation ecosystem dedicated to educational advancement.

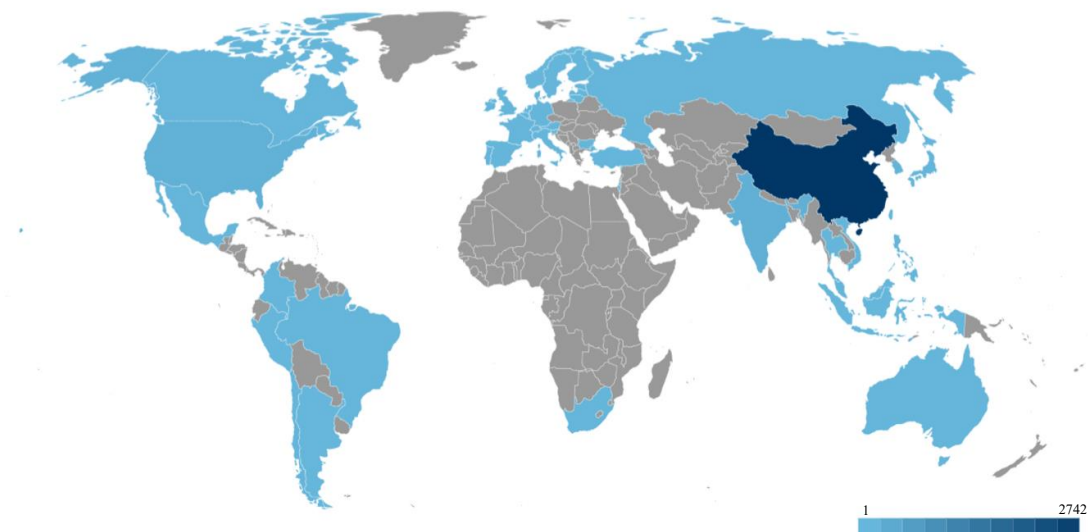
Figure 3(b) reveals a significant upward trend in patent filings related to didactic units applied to engineering education, particularly from 2018 onward, with notable exponential growth between 2021 and 2024. This temporal evolution suggests an increasing global interest in technological and methodological educational solutions

**Table 1** – Distribution of Technical and Scientific Production Identified in Patent and Scientific Literature Databases (n = 3,840 patents; n = 30 publications)

DATABASE	PATENTS	JOURNAL ARTICLES
Web of Science	0	6
Scopus	0	6
Google Acadêmico	0	18
Orbit	3.840	0

Source: Prepared by the authors (2025)

**Figure 2** – Global Landscape of Intellectual Property Protection in Didactic Units for Engineering Education (n = 2.986)



Source: Prepared by the authors (2025)

designed for engineering instruction, reflecting advances in open educational platforms, active learning methodologies, and growing demands for innovation in higher education.

From a cognitive perspective, this scenario may be interpreted as a reflection of ongoing transformations in contemporary educational paradigms, in which students increasingly assume an active role in the learning process. Such changes require new pedagogical approaches, often supported by didactic units, educational devices, and technological platforms. Patents in this domain therefore represent not only technical innovations but also emerging pedagogical concepts, including problem-based learning, project-based learning, and experiential learning approaches.

Overall, the findings demonstrate that the field of didactic units in engineering constitutes not only an area of educational development but also a domain of technological and economic competition. In this context, the ability to innovate and protect educational solutions through intellectual property mechanisms becomes a strategic advantage for institutions and countries seeking to lead the future of engineering education.

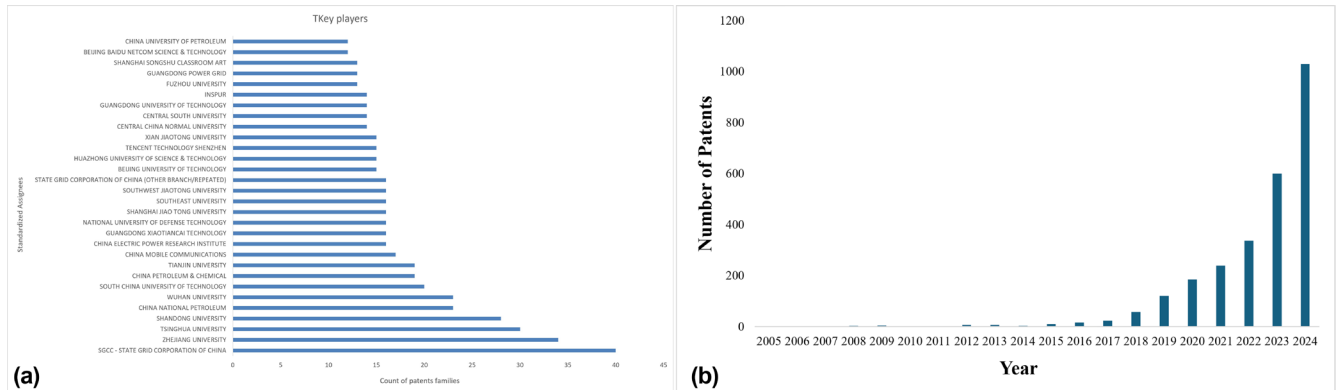
Figure 5 presents a technological landscape map organized by technical domain using a hexagonal cell structure, based on the classification of patent documents according to the World Intellectual Property Organization (WIPO) Technology Concordance framework. The technological fields are arranged according to patent density, ranging from red (high concentration) to light gray (low concentration), as indicated by the scale shown at the bottom of the figure.

The domains exhibiting the highest levels of technological activity include Computer Technology, IT Methods for Management, and Digital Communication, represented by red and orange tones. These areas indicate a high concentration of innovations and suggest a central role for digital technologies within contemporary educational strategies. Other domains demonstrating substantial technological activity include Medical Technology, Control, and Measurement, which are closely associated with automation, instrumentation, and medical simulation technologies.

Significant levels of patenting activity are also observed in Electrical Machinery, Apparatus, Energy, Telecommunications, and Semiconductors, suggesting a strong presence of electronic and computational technologies within technical and engineering education environments. These findings reflect the growing integration of digital tools, intelligent systems, and automated processes into educational settings, particularly in disciplines that require practical and technology-intensive learning experiences.

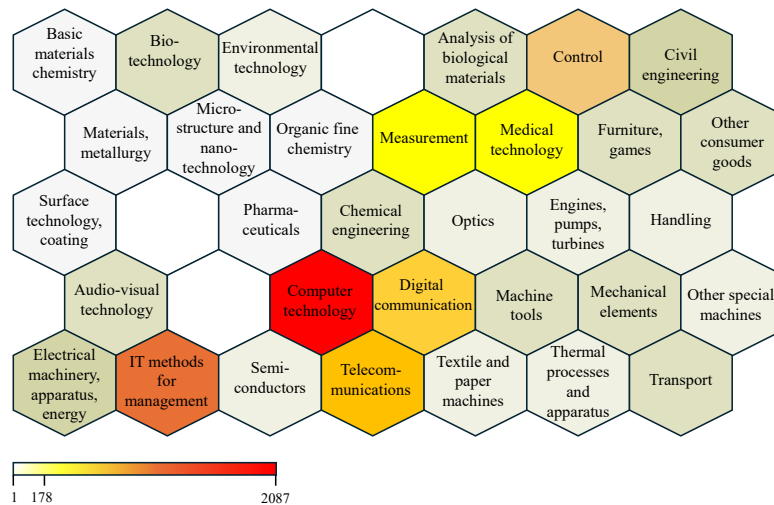
In contrast, domains such as Environmental Technology, Organic Fine Chemistry, and Biotechnology exhibit relatively low patent densities. This finding may indicate underexplored opportunities for the development and application of educational technologies within these fields. Expanding innovation efforts in these areas could contribute to the diversification of didactic solutions and support emerging educational demands related to sustainability, green technologies, bioprocesses, and advanced chemical engineering applications.

**Figure 3** – Overview of patents related to didactic units applied to engineering: (a) contributions by organization (n = 2,986); (b) temporal evolution (2005-2024)



Source: Prepared by the authors (2025)

**Figure 5** – Distribution of technological intensity across technical domains applied to engineering education (n = 2986)



Source: Prepared by the authors (2025)

Overall, the technological landscape demonstrates that innovation in didactic units applied to engineering education is strongly concentrated in digital and information-based technologies. This pattern reflects broader trends associated with digital transformation, Industry 4.0, and the increasing use of intelligent educational systems, while simultaneously highlighting opportunities for future technological development in less represented domains.

Table 2 summarizes the patents analyzed, which present educational solutions based on digital technologies, with a particular emphasis on automation and control applied to technical and scientific learning processes. The active patent CN113935871A describes an instructional system composed of five interconnected modules designed to transform written content into animated and visually enriched learning experiences.

The first module converts textual material into structured animations, where major animations correspond to chapters, branched animations represent subsections, and detailed animations correspond to specific knowledge points, allowing direct access to the relevant exercise page. The second module employs educational intelligence mechanisms to automatically identify and highlight priority content, thereby guiding students' study activities. The third module generates three-dimensional mind maps and evaluates student progress based on interactions with the learning interface. The fourth module incorporates exercises and real-world assessment questions, recording accuracy rates, displaying progress indicators, and automatically integrating incorrectly answered questions into personalized review plans. The fifth module provides student rankings and recommends additional exercises to strengthen areas in which performance remains below expected levels.

The inactive patent CN115035753B likewise proposes a five-module integrated system designed to support the teaching of Chemical Engineering principles through a cloud-based virtual classroom environment assisted by a chatbot. Student progression is conditioned upon successful completion of assessment tests, ensuring the consolidation of knowledge at each instructional stage. The modules include: theoretical foundations supported by a question bank; professional ethics and the contributions of notable figures in the field; virtual simulation experiments with learning records managed through big-data algorithms; in-person laboratory experiments accompanied by the preparation of technical reports; and simulations involving equipment design, chemical manufacturing processes, and operational safety practices.

Both patents demonstrate considerable potential for application within Brazilian higher education institutions and could be adapted to local educational contexts and the specific objectives of Chemical Engineering programs. Considering that most higher education institutions already maintain virtual learning environments, such systems could be implemented either as standalone platforms or as integrated solutions. Their adoption could foster active learning experiences, enhance student interaction with core disciplinary content, and help mitigate existing infrastructure limitations, particularly in institutions facing constraints related to laboratory facilities and technological resources.

Table 3 reveals considerable methodological diversity in the didactic approaches applied to Chemical Engineering education and related fields, highlighting ongoing efforts to align academic training with the contemporary demands of scientific and engineering education. For instance, the study conducted by Delgado and Fonseca-Mora (2010) presents a didactic unit focused on the teaching of unit operations, whose primary contribution lies in promoting conceptual and practical understanding through applied instructional activities.

However, the proposed approach remains largely confined to the manual execution of operations and does

not address key elements of modern instrumentation, such as sensors, actuators, or automated control systems. Consequently, its alignment with the competencies required by Industry 4.0 remains limited.

In contrast, the work of Battisti et al. (2019) stands out for its practical and technologically advanced approach by proposing educational experiments that directly integrate automation and process control concepts. Students are engaged in the development of prototypes including a heat exchanger, a humidification tower, and a tray dryer, incorporating sensors, microcontrollers (Arduino platforms), and closed-loop control strategies. These applications involve the monitoring and manipulation of variables such as flow rate, temperature, humidity, and mass loss, providing an educational experience closely aligned with the technical foundations of industrial instrumentation.

Such an approach contributes not only to the understanding of the underlying physicochemical phenomena but also to the development of competencies in automation, control logic, and systems integration, all of which are essential skills for contemporary chemical engineers. By combining theoretical knowledge with hands-on experimentation and digital technologies, the proposal reflects the growing convergence between engineering education and industrial digitalization.

Other studies, including those by Silveira (2022), Mugica (2022), and Neto (2022), broaden the scope of didactic units by addressing, respectively, industrial process modeling and simulation, the use of spectrophotometry in accessible educational contexts, and environmental education grounded in the Science, Technology, Society, and Environment (STSE) approach. These initiatives contribute valuable pedagogical perspectives and promote active learning strategies within engineering education.

Despite the educational relevance of these proposals, they generally do not incorporate process control technologies in a structured manner, revealing a persistent gap in the integration of technical education with emerging technological resources. This limitation suggests that many

**Table 2** – Patents related to didactic units applied to chemical engineering education

PATENT REGISTRATION	TITLE	DESCRIPTION
CN115035753	Teaching system based on chemical engineering principle experiment course	Modular teaching system integrating theory, virtual simulation, and practical experimentation for Chemical Engineering principles, with assessments incorporated into each module.
CN113935871	BIM live-action simulation+3D progress thinking guide diagram-based constructor examination learning system	Simulation-based learning system utilizing BIM and three-dimensional mind maps, featuring interactive modules composed of animations and exercises.

Source: Prepared by the authors (2025)

instructional approaches continue to emphasize conceptual learning while providing limited exposure to the digital and automated systems increasingly prevalent in modern industrial environments.

Overall, the studies analyzed reinforce the importance of didactic units as tools for active and meaningful learning. At the same time, they reveal the need to increase their technical sophistication through the incorporation of solutions based on automation, advanced simulation, artificial intelligence, and intelligent control systems. Such developments would better prepare future chemical engineers to address the challenges associated with digital transformation, sustainability, industrial modernization, and the technological transitions that characterize contemporary industry.

The combined analysis of patents and scientific publications reveals both advances and gaps in the development of didactic units for Chemical Engineering education. The patents **CN113935871A** and **CN115035753B** describe systems structured around five interconnected modules that incorporate virtual simulation, educational intelligence, automated assessment, and laboratory experimentation. These systems promote active learning and enhanced interaction with core disciplinary content, although their implementation would require adaptation to the Brazilian educational context.

Within the scientific literature, studies such as Delgado and Fonseca-Mora (2010) present didactic units focused on

unit operations. However, these approaches remain largely limited to manual procedures and do not integrate modern instrumentation or automated control systems. In contrast, Battisti et al. (2019) represent a significant advancement by combining sensors, microcontrollers, and closed-loop control strategies, thereby fostering technical competencies that are closely aligned with the requirements of Industry 4.0.

Other studies (Silveira, 2022; Mugica, 2022; Neto, 2022) broaden the scope of educational approaches by incorporating process modeling, simulation, and environmental education. Nevertheless, these initiatives do not systematically integrate automation and process control technologies into their instructional frameworks. Collectively, the literature demonstrates that, although isolated initiatives exhibit considerable pedagogical and technological relevance, the limited number of patents specifically dedicated to Chemical Engineering education and the methodological dispersion observed among scientific studies reveal persistent gaps in the consolidation of innovative educational solutions.

These findings indicate the need for integrated didactic units capable of combining laboratory experimentation, automation, process control, simulation, artificial intelligence, and digital learning environments. Such approaches would better prepare future chemical engineers to address the challenges associated with digital transformation, sustainability, industrial modernization, and the increasing technical complexity of contemporary engineering practice.

**Table 3** – Articles on didactic units applied to chemical engineering education, 2009-2025

TITLE	AUTHOR	AREA	DESCRIPTION
The use of co-operative work and rubrics to develop competences	Delgado, M. A; Fonseca-Mora, M. C. (2010)	Chemical Engineering	Discusses the application of a didactic unit in Chemical Engineering aimed at developing competencies in unit operations.
Studentes bulding didactic experiments as a tool for teaching unit operations and process control for chemistry technicians	Battist, R. <i>et al.</i> , (2019)	Chemical Engineering	Proposes the construction of didactic experiments involving heat exchangers, adsorption, humidification, and drying.
Study of Modeling and Simulation of a Didactic Plant MTX-Lab	Silveira, L. A., (2022)	Engineering	Presents a didactic plant designed for process modeling and simulation.
PhotometrixPro®: An Alternative for Spectrophotometric Practices in Biochemistry Education	Mugica, P. M., (2022)	Biochemistry	Supports the understanding of Biochemistry content.
A Multistrategic Didactic Unit Proposal for Teaching Heavy Metal Pollution and Remediation in Environmental Chemistry Education from a Science–Technology–Society–Environment Perspective	Neto, G. S. P., (2022)	Environmental Chemistry	Proposes a multistrategic didactic unit for teaching heavy metal pollution and remediation in Environmental Chemistry.

Source: Prepared by the authors (2025)

## 4 Final Considerations

The analysis of scientific and technological data revealed an uneven landscape regarding the development of didactic units for Chemical Engineering education. Despite the strategic importance of this field to the industrial sector, there is a significant shortage of low-cost educational materials specifically designed for Chemical Engineering, particularly within the context of public education. The findings indicate that most innovations are concentrated in areas such as robotics, computer science, and artificial intelligence, whereas traditionally experimental disciplines, such as Chemistry, continue to receive comparatively limited attention.

Brazilian scientific production stands out in terms of the volume of publications; however, this productivity is not reflected in a corresponding number of patent filings. This discrepancy highlights a gap between the academic knowledge generated and its transformation into protected technological solutions that can be effectively applied in educational settings. Only two Chinese patents, one active and one inactive, were identified as being directly related to Chemical Engineering education, revealing a substantial deficiency in the development of customized educational technologies for this field.

Furthermore, the data demonstrated a strong geographical and institutional concentration of patent activity, with a predominance of Chinese universities and companies. This pattern reflects the existence of robust public policies aimed at encouraging technological innovation and intellectual property protection, in contrast to the reality observed in many Latin American countries.

The analysis also identified the increasing adoption of emerging technologies such as Building Information Modeling (BIM), three-dimensional simulations, and artificial intelligence within educational systems, particularly in initiatives designed to promote active and personalized learning. The integration of these technologies into didactic units represents a promising strategy for overcoming the structural limitations faced by many Brazilian institutions, especially those located in regions distant from major urban centers.

The use of open platforms, low-cost devices, and competency-based educational methodologies can facilitate meaningful learning experiences even in environments with limited infrastructure. Such approaches offer opportunities to democratize access to high-quality engineering education while aligning instructional practices with the technological demands of contemporary industry.

Therefore, fostering the development of low-cost didactic units aligned with current curriculum guidelines and digital transformation initiatives should be considered

a strategic priority. Such efforts can contribute to greater equity, innovation, and quality in Chemical Engineering education, while simultaneously strengthening the capacity of educational institutions to prepare professionals capable of addressing the technological and industrial challenges of the twenty-first century.

## 5 Future Perspectives

The evolution of educational technologies has driven the development of increasingly sophisticated instructional systems, particularly through the incorporation of virtual simulations, Augmented Reality (AR), and Virtual Reality (VR). These resources enable the implementation of experimental activities within digital environments, helping to mitigate the shortage of laboratory infrastructure frequently encountered in Chemical Engineering programs. The simulation of industrial processes allows students to develop technical competencies in a safe, accessible, and controlled setting.

Recent advances include the integration of Artificial Intelligence (AI) and machine learning into educational platforms, enabling adaptive learning systems capable of personalizing instruction, providing real-time feedback, and generating realistic simulations based on Digital Twin technologies. These innovations strengthen data-driven learning approaches and facilitate the understanding and internalization of complex engineering processes.

In addition, the use of open-source platforms such as Raspberry Pi supports the development of modular, low-cost, and highly replicable didactic units. This technological convergence expands access to experimental learning opportunities and promotes the creation of hybrid and sustainable learning environments, which are increasingly essential for contemporary Chemical Engineering education. By combining digital technologies, practical experimentation, and intelligent learning systems, these approaches contribute to the development of technical, analytical, and problem-solving skills required by modern industrial environments and the broader context of digital transformation.

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