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Mapping Co-Curricular and Industry-Collaborative Learning in Foundational Chemical Engineering Courses: A Scoping Literature Review

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Abstract

Industry-collaborative and co-curricular learning experiences have been recognized as valuable components of engineering education, particularly in helping students connect disciplinary knowledge with professional practice. This paper presents a scoping review of recent peer-reviewed literature (2020-2025) examining how these experiences are described, positioned, and assessed in undergraduate chemical engineering education. Guided by the PRISMA-ScR framework, five journal articles were identified and synthesized. Results indicate that industry-collaborative learning is most often situated in upper-division or program-level contexts and is primarily designed to support professional and transferable skills, student engagement, and workplace competency. Explicit attention to conceptual understanding of foundational chemical engineering principles and direct assessment of this learning were limited across studies. These findings highlight a gap between the stated goals of contextualizing core concepts and the evidence used to demonstrate conceptual learning, suggesting a need for more intentional design and assessment of industry-collaborative learning in early chemical engineering curricula.

Introduction

Industry engagement and exposure to authentic engineering contexts through interaction with professional practices have long been recognized as critical components of engineering education, particularly in helping students connect disciplinary knowledge with professional practice and develop the competencies required for engineering work [1], [2]. Through workplace-aligned projects, co-curricular design teams, and work-integrated learning experiences, exposure to real or simulated engineering practice has been shown to support the development of professional and transferable skills, including teamwork, communication, and problem-solving, while also shaping students' understanding of engineering work and professional expectations [1], [3]. Despite this recognition, industry engagement in undergraduate engineering education has most often been formalized through senior design or capstone projects, in which students work on open-ended problems that resemble professional engineering practice and frequently involve external partners [4], [5]. Shah and Gillen (2024) concluded from a systematic review of university-industry partnerships that concentrating authentic, practice-based learning experiences primarily in the final years of undergraduate programs creates a curriculum gap in the middle years, leaving students with limited opportunities to develop professional understanding during the earlier stages of their degrees [6].

In chemical engineering programs, this curricular gap is particularly salient. Many undergraduate courses prior to the capstone emphasize theoretical and analytical foundations, and foundational courses, including material and energy balances, thermodynamics, fluid mechanics, heat and mass transfer, and process control, play a critical role in developing students' conceptual understanding and disciplinary expertise [7]. An emphasis on theory reflects intentional pedagogical choices aimed at building strong analytical foundations; however, the extent to which these courses make explicit connections to professional engineering practice depends on instructional approach. Research suggests that when foundational courses are delivered primarily through traditional, deductive methods, students may perceive them as abstract or disconnected from real-world engineering contexts [8], [9], [10]. In contrast, inductive and context-driven pedagogies have been shown to strengthen students' ability to connect core concepts with authentic engineering problems [8]. Given that foundational courses constitute a substantial portion of the undergraduate curriculum and are where disciplinary expertise first develops, their design plays a central role in shaping how students integrate conceptual knowledge with professional practice.

In response to these concerns, instructors have explored co-curricular and industry-collaborative learning experiences to introduce professional context into chemical engineering education. Reported approaches include course-embedded industry projects, co-curricular competition or project teams, work-integrated learning models, and industry-simulated environments that approximate professional practice [11], [12], [13], [14]. These approaches are typically motivated by goals of contextualizing abstract concepts, increasing student engagement, and supporting preparation for professional practice and work readiness [1], [12], [13]. However, the design and implementation of these learning experiences vary widely in structure, scope, and the extent to which industry partners are directly involved, and it is not yet clear where in the undergraduate curriculum such experiences are being situated or what they are designed to achieve in terms of disciplinary learning.

Although co-curricular and industry-collaborative learning experiences are increasingly reported in engineering education, a systematic synthesis of how they function within foundational chemical engineering courses specifically has not yet been conducted. Industry engagement is often done broadly across disciplines or focuses primarily on capstone and senior-level contexts [4], leaving limited clarity about how and whether such experiences are integrated into the earlier, theory-intensive stages of chemical engineering programs [7]. Prior work has also noted substantial variation in how learning outcomes, particularly conceptual understanding in engineering science domains, are reported and assessed in experiential educational contexts [17], raising questions about the strength of the evidence supporting claims for these approaches.

To address this gap, this study conducts a scoping review of recent research on co-curricular and industry-collaborative learning in undergraduate chemical engineering education, with particular attention to foundational course contexts. Using the PRISMA-ScR framework [16], it maps how these experiences are described and positioned within the curriculum, identifies common themes in their design and implementation, and examines how learning outcomes and assessment approaches are reported. The guiding research question is: *How does the existing literature characterize co-curricular and industry-collaborative learning experiences within undergraduate chemical engineering education, and to what extent are foundational course contexts represented?*

Methodology

This study employed a scoping literature review to map and characterize how co-curricular and industry-collaborative learning experiences are described and reported within undergraduate chemical engineering education, with particular attention to foundational course contexts. A scoping review approach was selected because the study was exploratory and descriptive, focusing on the design, implementation, and reporting of learning experiences across diverse instructional contexts rather than evaluating effectiveness or synthesizing outcomes quantitatively. Scoping reviews are particularly well-suited for examining emerging or heterogeneous bodies of literature and for identifying gaps in existing research [16], [18]. The review was conducted in alignment with the PRISMA Extension for Scoping Reviews (PRISMA-ScR) to ensure transparency and rigor in the identification, screening, and inclusion of studies [16].

Literature Identification and Database

The review focused on peer-reviewed journal articles published between 2020 and 2025. This timeframe was selected to capture recent developments in industry-collaborative and co-curricular approaches within chemical engineering education while maintaining a focused and manageable scope. A structured search was conducted in Scopus, selected for its comprehensive indexing of peer-reviewed engineering education journals and its ability to support consistent, reproducible searches across publication venues.

The search targeted three journals central to chemical engineering and engineering education research: *Journal of Engineering Education (JEE)*, *Chemical Engineering Education (CEE)*, and *Education for Chemical Engineers (ECE)*. These journals were selected because they represent the primary peer-reviewed venues for research on chemical engineering pedagogy and engineering education more broadly, and they consistently publish studies on instructional design and learning outcomes in undergraduate engineering contexts. Journal articles were prioritized to focus on archival, peer-reviewed studies that provide sufficient methodological detail on instructional design, industry involvement, and assessment to support cross-study comparison, consistent with the descriptive and mapping goals of this review. It should be noted that this focus on journal articles excludes conference proceedings, including ASEE annual conference papers, which are a common venue for reporting instructional innovations in chemical engineering education. Searches were applied to article titles, abstracts, and keywords to identify studies describing co-curricular or industry-collaborative learning experiences embedded within or directly connected to undergraduate chemical engineering curricula.

Search String Strategy

Search terms were developed iteratively to reflect the language commonly used in the engineering education literature to describe foundational coursework and authentic learning experiences. Initial keywords were drawn from prior studies on experiential, practice-based, and industry-engaged learning, as well as from preliminary scans of relevant article titles and abstracts within the target journals. These terms were refined through iterative testing to balance inclusivity and specificity. For example, early search strings that relied solely on the term "industry partnership" were expanded to include "industry-collaborative" and "work-integrated" learning after preliminary scans revealed that relevant studies used varied terminology to describe similar forms of professional engagement.

Boolean-based search strings combined terms related to chemical engineering education, undergraduate or foundational course contexts, and learning experiences described as real-world, practice-based, work-integrated, co-curricular, experiential, or industry-collaborative. Three

Boolean search strings were finalized to capture disciplinary and terminological variation across journals and were applied consistently across the selected publication venues. The full search strings are presented in Table 1.

Table 1. Boolean Search Strings

Search String	Subject Areas and Research Contexts
1	(“chemical engineering” OR “engineering education”) AND (“sophomore” OR “junior” OR “middle years” OR “undergraduate” OR “university”) AND (“industry” OR “industrial” OR “partnership” OR “collaboration”)
2	(“chemical engineering” OR “engineering education”) AND (“sophomore” OR “junior” OR “middle years” OR “undergraduate” OR “university”) AND (“real-world” OR “authentic” OR “practice-based” OR “work-integrated” OR “co-curricular” OR “experiential” OR “problem-based” OR “theory to practice”)
3	(“chemical engineering” OR “engineering education”) AND (“sophomore” OR “junior” OR “middle years” OR “undergraduate” OR “university”) AND (“foundational” OR “course” OR “curriculum”)

Search Result and Data Management

The database search retrieved records from all three journals, which were exported to a spreadsheet for screening and data management. Duplicate records were removed prior to screening. Study selection followed a three-stage process: title, abstract, and full-text screening guided by predefined inclusion and exclusion criteria (Table 2).

During title screening, records clearly outside undergraduate chemical engineering or unrelated to co-curricular or industry-collaborative learning were excluded. Abstract screening retained studies describing structured learning experiences within chemical engineering coursework that incorporated authentic professional or industry contexts, such as direct industry collaboration, use of real industrial data or case studies, engagement with practicing engineers, industry-sponsored projects, realistic simulations, or practice-oriented design experiences.

Full-text screening confirmed alignment with the review scope. Alignment required implementation within undergraduate chemical engineering programs, integration into formal coursework or program-level initiatives with curricular linkage, and relevance to foundational rather than exclusively capstone-course contexts. Studies were excluded if they focused solely on senior capstone design, standalone internships or work placements without curricular integration, graduate-level education, or non-chemical engineering populations. Studies were included only if they provided sufficient detail regarding instructional design, the nature of industry involvement, student activities, and reported learning outcomes to support meaningful cross-study comparison.

Table 2. Study Inclusion and Exclusion Criteria

Category	Inclusion Criteria	Exclusion Criteria
Population	Undergraduate chemical engineering students	Graduate-only, K–12, or non–chemical engineering populations
Course Context	Undergraduate chemical engineering coursework or program-level learning experiences connected to the curriculum, with attention to foundational course contexts	Studies situated exclusively in senior capstone design courses without integration of foundational or middle-year course contexts
Learning Experience	Structured co-curricular or industry-collaborative learning experiences embedded within or directly connected to coursework	Standalone internships, co-ops, or extracurricular activities without curricular integration
Industry Involvement	Explicit engagement with industry professionals, industry contexts, or authentic engineering practice	No industry or professional context described
Publication Type	Peer-reviewed journal articles	Review articles, editorials, opinion pieces
Language	English-language publications	Non-English publications

Data Extraction and Synthesis

Data were extracted from the included studies using a structured data charting form developed in alignment with the review objectives. The charting form captured the following categories for each study: publication year, course or program context, type of co-curricular or industry-collaborative learning experience, nature and depth of industry involvement, reported learning outcomes, and assessment approaches used. This form provided the basis for the summary presented in Table 3.

The extracted data were synthesized using a thematic approach combining deductive and inductive analysis. Deductive coding was guided by the predefined charting categories derived from the review objectives, specifically examining how learning experiences were positioned within the curriculum, how industry collaboration was operationalized, which learning outcomes were emphasized, and how those outcomes were assessed. Inductive analysis was then applied to identify recurring patterns and variations not fully captured by the predefined categories, such as differences in the depth of industry engagement or differences in how professional skill development was framed relative to conceptual learning outcomes. This combined deductive-inductive approach enabled systematic comparison across studies while remaining responsive to themes emerging directly from the data, consistent with established practices in scoping review synthesis [18], [19]. Findings are presented narratively and through summary tables to highlight trends and gaps in the literature.

Results and Discussion

The database search yielded 604 records across the three journals. After removal of duplicates (n = 299), 305 records underwent title screening, followed by abstract screening (n = 182) and full-text article evaluation (n = 14). Five studies met all inclusion criteria and were retained for data charting and synthesis (Figure 1). All five included studies were published in Education for Chemical Engineers between 2020 and 2025. No eligible studies from the Journal of Engineering Education or Chemical Engineering Education met the inclusion criteria during the review period. Articles from these journals were most commonly excluded at full-text review because they focused exclusively on senior capstone design, standalone internships or work placements without curricular integration, graduate-level education, or non-chemical engineering contexts.

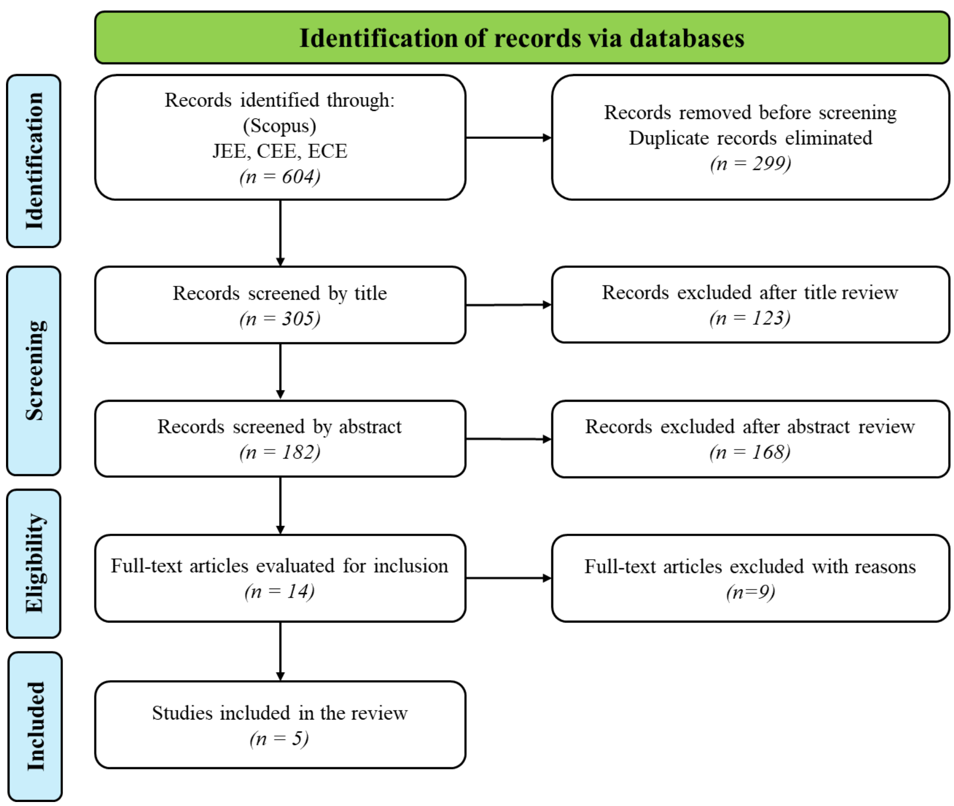

Figure 1. PRISMA flow diagram of the scoping review

The five included studies examined co-curricular and/or industry-collaborative learning experiences embedded within or formally connected to undergraduate chemical engineering programs. Collectively, they provide insight into how such experiences are characterized, where they are positioned within the curriculum, and how learning outcomes are reported and assessed. Table 3 summarizes key characteristics of the included studies.

Although only five studies met the inclusion criteria, this limited number appears to reflect both the specificity of the review focus and a relative scarcity of published research explicitly examining industry-collaborative or co-curricular learning experiences within foundational chemical engineering coursework. Many articles identified during full-text screening focused exclusively on senior capstone design, standalone internships, graduate-level education, or extracurricular initiatives without clear curricular integration. The small number of eligible studies, therefore, highlights a potential gap in the literature rather than a consequence of overly restrictive criteria alone. In this context, a scoping review remains appropriate, as its purpose is to map the extent and characteristics of available evidence in emerging or under-examined areas.

Table 3. Summary of Included Studies on Co-Curricular and Industry-Collaborative Learning in Chemical Engineering

Study	Year	Course / Program Context	Type of Learning Experience	Nature of Industry Involvement	Reported Learning Outcomes	Assessment Approaches
Nieto Bermejo et al. (2025) [20]	2025	Extracurricular competition team formally linked to undergraduate and master's programs through thesis work; multidisciplinary team spanning six engineering disciplines; 18-month project cycle	Competition-based, project-oriented co-curricular experience across multiple editions since 2014	Competition design constraints; material and technical sponsorship from Repsol and Graphenano Nanotechnologies	Application of foundational concepts (heat/mass transfer, fluid mechanics, process control, energy balances) mapped to Bloom's levels 5-6; teamwork, leadership, communication; professional and engineering identity development	Likert-scale survey (n=12), open qualitative responses; instructor-conducted Bloom's taxonomy mapping of learning activities without a formal rubric
Reedy et al. (2020) [21]	2020	Upper-division elective course (6th-8th semester); chemical and food engineering; maximum 20 students; private university, Colombia	Project-based non-placement work-integrated learning using the IPPD problem-solving framework; industry-based authentic challenges over 8 weeks (extended to 16 weeks after feedback)	Industry partners defined project challenges, provided weekly consultant feedback (20 min/week), and contributed to the final grade; no formal placement	Teamwork and creativity as targeted employability skills; professional identity development (pre-professional engineer identity); student engagement and intrinsic motivation	Multi-source qualitative design: student surveys, three focus groups, semi-structured industry partner interviews, lecturer written reflections; dual independent thematic coding; data triangulation across four sources
Rumayor et al. (2024) [22]	2024	Fourth-year compulsory Life Cycle Assessment course; European Project Semester (EPS) program; maximum 10 students; University of Cantabria, Spain	Industry-collaborative project-based learning (Learning by Doing); 16-week iterative activity; public oral defense with industry representatives present	Direct collaboration with regional companies; iterative real data access; panel of experts (companies, lecturers); industry present at final public defense	Problem-solving, critical thinking, applied LCA competencies; information management, analysis and synthesis; 71% of students self-reported applying knowledge	Multi-component rubric: weekly session participation (30%), final report and oral defense (50%), competency observation (20%); pre/post competency self-assessment survey (anonymous); grade improvement across two cohorts (7.4 to 8.0/10, T=0.08, non-significant)
Lim et al. (2022) [23]	2022	Second-year specialized undergraduate course in current Good Manufacturing Practices (cGMP); pharmaceutical engineering program;	Model-based experiential learning; instructor-constructed fictitious pharmaceutical company (XANDAR); 3D virtual and 3D printed plant models compared across three cohorts (n=197)	No real industry partner; instructor-designed industrial simulation justified by safety and access constraints preventing real pharmaceutical plant visits; fictitious	Conceptual understanding of cGMP and pharmaceutical manufacturing processes; student engagement and visualization; prospective curriculum alignment with foundational courses	Self-assessment survey (n=197, 17-item Likert); gamified quiz with ANOVA and Cohen's d analysis (d=0.54, medium positive effect for 3D printed model vs. control); sentiment analysis

		Singapore Institute of Technology		company with an authentic process flow diagram and GMP guidelines	(mass/energy balances, unit operations, reaction engineering, fluid mechanics)	
Castello et al. (2023) [24]	2023	University Extension Diploma in Food Technology (DEUTA); post-degree continuing education; 33.5 ECTS across 18 food sector modules; 15+ years of operation (since 2004/05); Universitat Polytechnic de Valencia, Spain	Structured diploma combining industry co-teaching (50% of instructional hours, mandated by institutional regulation) with a 250-hour remunerated industry placement	Industry professionals co-deliver 50% of content across 18 modules (regulatory requirement); curriculum sectors co-selected with regional industry federation (FEDACOVA); dual supervisor assessment of internship reports (UPV and company); industry present at closing seminar	Professional skills, employability, and lifelong learning; 44.8% of alumni (n=58, retrospective, 15 editions) reported meaningful labor market contribution; subsequent hiring by internship companies was reported.	Institutional quality survey (15 editions, 15-item Likert, avg. response 75%); retrospective alumni survey (n=58, Google Forms); structured internship reports with dual supervisor sign-off; company supervisor survey (n=18 company representatives)

Characterization of co-curricular and industry-collaborative learning experiences

Across the reviewed studies, co-curricular and industry-collaborative learning experiences were predominantly characterized as experiential, project-based activities designed to situate chemical engineering learning within authentic or professionally relevant contexts (Table 3). These experiences included competition-based projects aligned with industry practices [20], course-embedded work-integrated learning activities that did not involve formal industry placements [21], industry-partnered project-based learning focused on sustainability and life cycle assessment [22], a model-based experiential learning environment built around a fictitious pharmaceutical manufacturer [23], and a structured diploma program combining industry co-teaching with sustained industry placements [24].

Industry collaboration was implemented across a wide spectrum of forms and depths, ranging from instructor-constructed simulation with no real industry partner to structurally mandated co-delivery by industry professionals. In some studies, industry partners contributed primarily by shaping problem contexts, defining project briefs, offering feedback on student work, or providing mentorship [21], [22]. In one study, industry involvement took the form of a simulated environment, a fictitious pharmaceutical company designed entirely by the instructors, in which no real industry partner was engaged [23]. One study described a more sustained form of collaboration in which industry professionals co-taught 50% of instructional hours, and students completed a 250-hour remunerated placement in a food company [24]. Altogether, the papers included in this study illustrated how industry-collaborative learning in chemical engineering can be implemented across a wide range of structural forms, and most framed the learning as contextual exposure to professional practice than as curriculum co-design or co-teaching.

Course Context and Curricular Positioning

The course contexts summarized in Table 3 show that co-curricular and industry-collaborative learning experiences were implemented primarily in later-stage undergraduate courses or structured program-level initiatives. These experiences were typically positioned as integrative or professionally oriented components of the curriculum rather than as early, theory-intensive core courses. Rumayor et al. (2024) described a learning-by-doing experience embedded in a fourth-year compulsory life cycle assessment course [22], while Lim et al. (2022) reported a simulated pharmaceutical production experience implemented in a second-year undergraduate course, the earliest curricular placement in the corpus [23]. Nieto Bermejo et al. (2025) described an extracurricular competition team formally linked to the curriculum through bachelor's and master's theses, spanning multiple years and involving students from six engineering disciplines [20]. Castelló et al. (2023) reported a post-degree university extension diploma that included undergraduate students, with industry professionals co-delivering 50% of the content across 18 food-sector modules [24].

Although the reported experiences drew on foundational chemical engineering principles, including heat and mass transfer, fluid mechanics, process design, and energy balances, none were embedded directly in early core courses, such as material and energy balances or introductory thermodynamics. Importantly, this distribution reflects the available literature rather than a screening restriction; studies describing industry-collaborative or co-curricular learning in early foundational courses were not identified during any stage of the search. Collectively, the findings suggest that such experiences are more commonly introduced after students have developed a baseline of disciplinary knowledge, leaving limited documented evidence of their integration within early foundational coursework and a corresponding gap in understanding how they might support conceptual learning at that stage of the curriculum.

Table 4 summarizes the relative curricular placement of each experience and the reported depth of industry engagement. Depth of engagement was categorized descriptively based on the form and continuity of industry involvement, ranging from contextual or simulated exposure (low) to advisory or project-framing roles (moderate) to sustained, direct collaboration, such as ongoing partnerships or structured placements (high). A notable pattern visible in Table 4 is that the experiences with the deepest structural industry involvement, Rumayor et al. (2024) and Castelló et al. (2023), are also those positioned furthest from early foundational course contexts. Conversely, the study with the earliest curricular placement, Lim et al. (2022), involved no real industry partner, with a professional context constructed entirely through simulation. This pattern suggests that depth of industry integration and proximity to foundational course contexts may present competing design considerations within the current literature.

Table 4. Curricular Positioning and Depth of Industry Engagement

Study	Course Level / Context	Form of Industry Engagement	Depth of Engagement
Nieto Bermejo et al. (2025) [20]	Extracurricular competition team; formally linked to undergraduate and master's curricula through thesis work; 18-month cycle across multiple editions	Competition-based design constraints; material and technical sponsorship from industry (Repsol, Graphenano); no direct educational collaboration with industry partners	**Low-Moderate**
Reedy et al. (2020) [21]	Upper-division elective; 6th-8th semester undergraduate	Industry partners defined project challenges, provided weekly advisory feedback (20 min/week), and contributed to the final student grade	**Moderate**
Rumayor et al. (2024) [22]	Fourth-year compulsory course	Direct collaboration with regional companies; iterative real data access throughout 16-week activity; industry present at final public defense	**High**
Lim et al. (2022) [23]	Second-year specialized undergraduate course	Instructor-constructed fictitious pharmaceutical company (XANDAR); no real industry partner; simulation justified by safety and access constraints preventing real plant visits	**Low**
Castello et al. (2023) [24]	Post-degree university extension diploma	Industry professionals co-deliver 50% of content (regulatory mandate); curriculum co-designed with regional industry federation; 250-hour remunerated placement with dual supervisor assessment	**High**

Reported Learning Outcomes

Across the reviewed studies, reported learning outcomes emphasized professional and transferable skills, including teamwork, communication, leadership, creativity, and student engagement (Table 3). Nieto Bermejo et al. (2025) described leadership and teamwork development arising from sustained participation in multidisciplinary, competition-based project teams that require coordination, decision-making, and iterative problem-solving [20]. Reedy et al. (2020) emphasized creativity and employability-related competencies developed through project-based coursework in which students engaged with open-ended, industry-framed challenges [21]. Castelló et al. (2023) documented professional skill development and employability outcomes across fifteen editions of an industry-integrated diploma program, with 44.8% of longitudinal survey respondents reporting that the program contributed meaningfully to their access to the labor market [24]. Other studies reported increased student motivation and enhanced perceptions of the relevance of chemical engineering coursework to professional practice [22], [23].

Explicit reporting of conceptual learning related to foundational chemical engineering principles was limited across the reviewed studies. Only two studies articulated specific foundational concepts in connection with reported learning outcomes. Lim et al. (2022) reported quiz-assessed technical understanding within a simulated pharmaceutical manufacturing environment and outlined a prospective curriculum integration vision connecting the model plant to mass and energy balances, unit operations, reaction engineering, and fluid mechanics, though this broader integration had not yet been implemented or assessed at the time of the study [23]. Nieto Bermejo et al. (2025) provided a detailed mapping of foundational concepts to learning activities in the corpus, connecting all four competition projects to named course areas: heat and mass transfer, fluid mechanics, process control, and energy balances and to the higher-order cognitive levels of Bloom's revised taxonomy [20]. In both cases, however, students drew on disciplinary knowledge acquired in prior courses rather than demonstrating the acquisition of new foundational concepts through the experience itself. The remaining three studies made no explicit claim about foundational ChE conceptual learning, focusing entirely on professional skill development, employability, or applied sustainability competencies [21], [22], [24].

This pattern suggests that the literature in this study characterizes co-curricular and industry-collaborative learning primarily in terms of professional formation rather than disciplinary conceptual development, and that evidence of conceptual learning, when present, was typically inferred from participation in authentic tasks rather than assessed through targeted measures tied to core engineering science concepts [17].

Assessment Practices and Evidence of Learning

Assessment approaches across the reviewed studies relied predominantly on qualitative and self-reported measures, including student reflections, surveys, interviews, and course evaluations (Table 3). These methods were primarily used to capture students' perceptions of engagement, professional skill development, and the perceived relevance of coursework. Nieto Bermejo et al. (2025) assessed outcomes through a five-point Likert-scale survey combined with open qualitative responses, and mapped student work retrospectively to Bloom's revised taxonomy levels through instructor observation without a formal rubric [20]. Reedy et al. (2020) employed the most methodologically rigorous qualitative design in the corpus, combining student surveys, focus groups, semi-structured industry partner interviews, and lecturer written reflections with dual independent thematic coding [21]. Castelló et al. (2023) drew on four data sources across fifteen editions, an institutional quality survey, a retrospective survey from former students (n = 58), structured internship reports with dual supervisor sign-off, and a company supervisor survey (n = 18), representing the most temporally extensive evidence base in the corpus [24].

Direct assessment of conceptual understanding of foundational chemical engineering principles was comparatively rare. Only Lim et al. (2022) incorporated a performance-based measure, a gamified quiz administered across three cohorts, and reported inferential statistics, finding a medium-sized positive effect (Cohen's d = 0.54) for the 3D-printed model condition relative to the control [23]. However, the content of the quiz was not described in sufficient detail to confirm whether the questions targeted foundational course concepts or procedural knowledge specific to the cGMP context, and no pre-test was administered, precluding an estimate of learning gain. The remaining studies inferred conceptual learning from project participation, artifact completion, or industry engagement without direct measurement [20], [21], [22], [24].

Table 5 synthesizes the alignment between the emphasis on reported learning outcomes and the assessment approaches used across the included studies. As shown, professional and transferable skills were frequently reported but supported primarily by self-reported or qualitative evidence. Conceptual understanding of foundational course principles was assessed directly in only one study, and no study used a standardized or validated instrument to measure learning outcomes. Validated concept inventories for core chemical engineering domains, including thermodynamics, fluid mechanics, and transport phenomena, exist within the engineering education literature [17] but were not utilized in any included study. This absence limits cross-study comparability and constrains conclusions about the impact of co-curricular and industry-collaborative learning on foundational conceptual understanding. A further pattern visible in Table 5 is that two studies articulate explicit curriculum integration visions for foundational courses, Lim et al. (2022) and Nieto Bermejo et al. (2025), but neither implements nor assesses this integration within the reported study, reflecting a gap between conceptual ambition and assessment evidence that is a distinctive feature of this corpus.

Table 5. Alignment Between Learning Outcomes and Assessment Approaches Across Included Studies

Learning Outcome	Common Assessment Approaches	Observed Pattern
Professional and transferable skills (e.g., teamwork, communication, leadership, creativity)	Student surveys, reflections, interviews, and course evaluations	Outcomes were frequently reported but supported primarily by self-reported or qualitative evidence. In no case was professional skill development formally assessed using a validated instrument (e.g., leadership and teamwork documented through reflective accounts) [20]; creativity and teamwork were explicitly not formally assessed in the course [21].
Student engagement and motivation	Course evaluations, qualitative feedback, Likert-scale surveys, sentiment analysis	Engagement was commonly reported as a primary benefit but was rarely triangulated with independent data sources or measured longitudinally. Engagement was typically inferred from student feedback or course evaluations rather than from performance measures [20], [23], [24].
Application of existing disciplinary knowledge	Project artifacts, design reports, instructor-developed rubrics, oral defense	Application of disciplinary knowledge was frequently claimed but infrequently measured directly. Critically, in all cases where application was reported, students were mobilizing knowledge acquired in prior courses rather than demonstrating acquisition of new concepts through the industry-collaborative experience itself. The experience functions as a context for applying prior learning rather than as a vehicle for acquiring new foundational concepts [22], [23].
Conceptual understanding of foundational chemical engineering principles	Quizzes, performance-based tasks	Direct assessment was limited to a single study that used a gamified quiz with statistical analysis (ANOVA; Cohen's $d = 0.54$) [23]. However, quiz content was not described in sufficient detail to confirm alignment with foundational course concepts (e.g., heat transfer, thermodynamics, mass balances) rather than cGMP procedural knowledge. No other study directly assesses foundational course conceptual understanding.
Prospective alignment with foundational course learning objectives	Curriculum integration maps, Bloom's taxonomy mapping (instructor-assigned, no formal rubric)	Two studies articulated explicit visions for foundational course concept integration, Lim et al. (2022) through a curriculum map connecting XANDAR to mass/energy balances, unit operations, and reaction engineering across multiple courses [23]; Nieto Bermejo et al. (2025) through a Bloom's taxonomy mapping of all four projects to named foundational course areas [20]. In neither case was this vision implemented or assessed within the reported study.
Use of validated or standardized assessment instruments	Established or previously validated tools (e.g., concept inventories)	No study employed a standardized or validated instrument to assess any learning outcome, professional, affective, or conceptual. Validated concept inventories for core-course domains (thermodynamics, transport phenomena) exist within the engineering education research community [17] but were not adopted in any of the included studies, limiting cross-study comparability and constraining conclusions about the impact of these approaches on foundational learning.

Synthesis and Identified Gaps

The studies summarized in Tables 3, 4, and 5 collectively characterized co-curricular and industry-collaborative learning in chemical engineering as primarily oriented toward professional formation, workplace preparedness, and student engagement, with comparatively less emphasis on the explicit design of learning experiences to support conceptual understanding in foundational courses. While several studies described students drawing on disciplinary knowledge in authentic or industry-relevant contexts, none provided direct evidence that the industry-collaborative or co-curricular experience itself produced foundational concept acquisition as opposed to facilitating the application of knowledge already learned. The distinction between applying existing knowledge and acquiring new conceptual understanding through experience was not explicitly addressed in any of the included studies, yet it is central to evaluating whether these approaches can meaningfully contribute to foundational course learning.

A further pattern visible across the corpus was an inverse relationship between depth of industry integration and proximity to foundational course contexts. The experiences with the deepest and most sustained industry involvement were positioned at the advanced undergraduate or post-degree level and made no claims about foundational course conceptual learning, while the study with the richest foundational course concept articulation had the weakest evidence base. This pattern suggests that designing experiences that are both deeply integrated with industry and explicitly aligned with foundational conceptual learning objectives represents a challenge that may not yet have been systematically addressed. The observed variability in learning experience design, depth of industry involvement, and assessment approaches further reflected a fragmented evidence base and underscores the need for greater clarity and consistency in how co-curricular and industry-collaborative learning experiences are conceptualized, reported, and evaluated within chemical engineering education.

Implications

Across the five studies included in this review, co-curricular and industry-collaborative learning experiences in chemical engineering were described as supporting professional skill development, student engagement, and exposure to workplace practices. In contrast, explicit articulation of conceptual learning objectives tied to foundational chemical engineering principles was less consistently reported. For instructors and curriculum designers, this finding highlights an important distinction between designing experiences that allow students to apply existing disciplinary knowledge in authentic contexts and designing experiences that support the acquisition of new foundational conceptual understanding. In every included study, students applied knowledge already learned in prior courses rather than encountering foundational concepts for the first time through the industry-collaborative experience. Instructors with explicit foundational learning goals could consider how to sequence industry-collaborative activities relative to when concepts are first introduced in the curriculum, and could also adopt validated assessment instruments, such as concept inventories for thermodynamics or transport phenomena [17], that capture conceptual learning gains rather than perceived relevance alone.

For researchers and program planners, the review points to two underexplored considerations. First, industry engagement supports more than student motivation. Reedy et al. (2020) demonstrated that direct contact with industry contributes to pre-professional engineering identity formation, offering a more theoretically precise mechanism for why these experiences matter and a more productive framework for future research design [21]. Second, structural sustainability is a genuine design constraint that is rarely addressed explicitly. Castelló et al. (2023) documented that internship capacity, not pedagogical design, became the binding limitation on program scale over fifteen years, with company reluctance, supervision burden, and remuneration obligations identified as specific barriers [24]. More systematic reporting of instructional design features, intended learning outcomes, and the role of industry partners would strengthen the evidence base and enable clearer interpretation of when and how co-curricular and industry-collaborative experiences can support foundational learning in chemical engineering.

Conclusion and Future Work

This scoping review examined how co-curricular and industry-collaborative learning experiences are described, positioned, and assessed within undergraduate chemical engineering education, with particular attention to foundational coursework. Across the five included studies, co-curricular and industry-collaborative initiatives were most often reported as experiential or project-based approaches aimed at supporting professional formation, student engagement, and perceived relevance to practice. In contrast to prior reviews that have emphasized senior capstone design or cross-disciplinary industry engagement, this review mapped how such experiences are situated specifically within chemical engineering curricula. The available literature described initiatives that were primarily positioned in upper-division courses or program-level contexts, with comparatively fewer documented examples embedded within early, theory-intensive foundational courses.

Across the included studies, descriptions of industry involvement most frequently emphasized contextual, advisory, or collaborative roles, and reported outcomes centered largely on professional and transferable skills. Explicit articulation of conceptual learning objectives tied to core chemical engineering principles and the use of direct assessment strategies to foster disciplinary understanding were less consistently documented. As a result, the current evidence base provides limited insight into how industry-collaborative learning is intentionally aligned with foundational conceptual learning within chemical engineering programs.

Building on these findings, future research would benefit from further examination of co-curricular and industry-collaborative learning experiences situated within early foundational chemical engineering courses, where relatively few documented examples were identified in this review. Such investigations could explore how these experiences are conceptualized, implemented, and assessed in relation to disciplinary learning objectives in engineering science domains. In addition, greater attention to the development and reporting of assessment approaches that capture both professional competencies and conceptual understanding would strengthen the evidence base and enable more meaningful comparison across studies. Improved clarity and consistency in terminology, instructional design descriptions, and accounts of industry involvement would further support coherence in this area of research and provide a foundation for longitudinal and comparative studies examining how industry-collaborative experiences are integrated across the chemical engineering curriculum.

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