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PAPER

Students' Motivation in Challenge-Based Learning in Higher Engineering Education: A Scoping Review

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ABSTRACT

Challenge-based learning (CBL) emphasizes student-centered approaches that foster critical thinking, problem-solving, teamwork, and engagement through real-world challenges, preparing students for professional engineering careers. However, the motivational processes underpinning these outcomes have not been systematically explored. This scoping review aimed to identify and synthesize the effects of CBL on student motivation in higher engineering education, guided by Arksey and O'Malley's protocol. The protocol involved defining the research questions, selecting relevant studies, extracting and analyzing data, and collating and reporting findings. This scoping review examined literature from seven scientific engineering education databases published between 2015 and 2024, resulting in a final selection of 18 articles. The review identified several thematic areas—CBL's effects on students' intrinsic and extrinsic motivation, the enjoyment and engagement of real-world challenges application, the role of interdisciplinary collaboration and teamwork, the implications of real-world problem-solving for professional identity formation, and the teachers' role. The review also revealed the predominance of quantitative methodologies, including instruments such as the SRQ-A and MUSIC® model, in evaluating CBL's impact on motivation, while qualitative approaches, particularly those grounded in self-determination theory, are notably underrepresented. This methodological disparity constrains a comprehensive understanding of students' learning experiences and the contextual dynamics shaping motivation within CBL frameworks. These findings highlight the critical elements influencing student motivation in CBL contexts and provide insights into effective strategies for its implementation in higher engineering education.

KEYWORDS

student motivation, challenge-based learning (CBL), higher engineering education

1 INTRODUCTION

Challenge-based learning (CBL) has garnered attention in higher education as an innovative pedagogical approach that fosters student motivation, engagement, and professional skill development. This student-centered methodology involves

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learners collaborating with external stakeholders—such as industry and community partners—to address real-world challenges. CBL promotes interdisciplinary problem-solving and active learning while connecting academic work directly to professional contexts, making it a valuable tool for students' motivation, both intrinsic and extrinsic. Empirical evidence suggests that CBL has seen a significant increase in adoption across higher education institutions, particularly in engineering programs, due to its effectiveness in enhancing student engagement and professional preparedness [1], [2]. For higher engineering education, where students prepare to tackle complex societal issues such as climate change, renewable energy, and healthcare, CBL offers a compelling alternative to traditional learning models [3].

In recent years, engineering educators' teaching methods have shifted toward using active learning strategies to meet the evolving demands of the professional world and the unique traits of Generation Z students [4]. This shift reflects a growing recognition that education must adapt to the complexities of contemporary global challenges—such as climate change, technological advancements, globalization, and sustainable development engineering [5]. Despite these shifts, traditional teaching practices still dominate in many engineering programs, often failing to fully engage students or prepare them for real-world professional demands. Consequently, there is an increasing need to explore whether CBL effectively bridges this gap by fostering motivation and engagement in engineering students. This is underpinned by preparing students with technical expertise and cross-cutting skills such as teamwork, problem-solving, and collaboration. While CBL shares similarities with other active learning strategies, such as problem-based learning (PBL) and project-based learning (PrBL), it distinguishes itself by emphasizing external stakeholder involvement and tailoring challenges to students' future professional paths. PBL typically regulates small-group problem-solving without necessarily involving industry partners, while PrBL revolves around executing structured projects, often without real-world stakeholder cooperation [6], [7]. CBL, in contrast, integrates industry engagement as a core component, ensuring that students apply their knowledge in practical, professionally relevant contexts [8].

Research on implementing CBL has reported several positive outcomes, including enhanced industry networking, practical application of technical skills, improved problem-solving abilities, improved learning outcomes, and better collaboration within student teams. However, while these benefits have been documented, there remains a lack of comprehensive synthesis on how CBL specifically influences students' motivation. Existing studies are fragmented across different contexts and methodological approaches, making it difficult to draw overarching conclusions about the impact of CBL on student motivation [9]. Additionally, no review has systematically mapped the diverse research methodologies employed to study these motivational effects, which is crucial for developing a more robust understanding of CBL's effectiveness. This study makes a novel contribution by systematically mapping the effects of CBL on student motivation in higher engineering education while also identifying how different educational and methodological approaches have been applied in previous research. Unlike prior reviews that focus solely on student learning outcomes or engagement, this study uniquely synthesizes findings on both intrinsic and extrinsic motivation, providing a more holistic view of CBL's impact on engineering education practices.

To address these gaps, this scoping review aims to provide a structured synthesis of existing research on CBL and student motivation in higher engineering education. By doing so, it identifies key themes, trends, and gaps in the literature while offering insights into best practices and potential areas for future research. This review explores the effect of CBL on students' motivation in higher engineering education, with a particular focus on intrinsic and extrinsic motivation, student engagement, and perceptions of the learning experience from multiple perspectives, including students, teachers, and external stakeholders. Moreover, this review also examines the diverse educational frameworks and methodological approaches used in CBL-related research. It identifies trends in how CBL's effect on learning and motivation is measured quantitatively, qualitatively, or through mixed methods, thus offering insights into best practices and areas for future research. By systematically mapping these aspects, the review provides valuable insights for educators and education planners seeking to implement CBL effectively in higher engineering education, ensuring that teaching strategies align with the evolving demands of the professional world.

Given the pressing need to equip engineering students with both the technical expertise and the soft skills required to navigate today's complex global challenges, this scoping review provides a timely and essential contribution to the field by systematically mapping how CBL influences student motivation and how this effect has been studied [4], [10].

The findings from this review will provide a framework for understanding how the issue under consideration has been examined and how the different approaches could be used to harness effective and efficient mechanisms for implementing CBL across various disciplines and contexts. The following research questions guide the current study:

– What are the effects of CBL on student motivation in higher engineering education?
– How have different methodological approaches and motivational theories been applied to study the effect of CBL on student learning and motivation in higher engineering education?

2 METHODS

2.1 Scoping review protocol

This scoping review adhered to the methodological framework established by Arksey and O'Malley [11], which is widely recognized for systematically mapping key concepts, types of evidence, and research gaps in a field. This approach was chosen over systematic reviews or meta-analyses because it allows for a broad exploration of diverse study designs and methodologies without limiting the scope to a specific subset of studies. Unlike systematic reviews, which focus on synthesizing findings to answer a narrowly defined question, scoping reviews are more flexible and suited for identifying research trends, mapping methodological approaches, and highlighting gaps in the literature. The framework consists of five key stages: (i) formulating the research questions, (ii) identifying relevant literature, (iii) selecting the studies that meet the criteria, (iv) extracting and organizing the data (charting), and (v) synthesizing, summarizing, and presenting the findings.

2.2 Formulation of research questions

This scoping review was developed to explore the effects of CBL on students' motivation in higher engineering education. As highlighted above, the review sought to address two key research questions: (i) "What are the effects of CBL on student motivation in higher engineering education?" and (ii) "How have different educational and methodological approaches been applied to study the effect of CBL on student learning and motivation in higher engineering education?" The definition of CBL informed the formulation of the first research question. As highlighted above, the concept has been defined differently by different authors. However, for the purpose of this study, CBL in higher engineering education is defined as a student-centered method where learners collaborate with external stakeholders, such as industry and community partners, to address real-world challenges. This approach encourages interdisciplinary problem-solving, active learning, and professional growth while promoting both intrinsic and extrinsic motivation by engaging students in meaningful, authentic tasks directly connected to their future professional paths [8]. One critical aspect of CBL is the involvement of external stakeholders. A plethora of research demonstrates that such engagement enhances student motivation and relevance by connecting engineering knowledge to practical, real-world contexts [3]. The second research question guiding this study explores how various scholars have measured these effects, whether through quantitative or qualitative methods, across different contexts and disciplines.

This understanding is essential for evaluating the impact of educational interventions in higher education institutions. This could be achieved by examining the range of educational frameworks and research methodologies (quantitative, qualitative, and mixed methods) used to assess the effects of CBL while not limiting the focus to specific outcomes or challenges but to identify critical gaps and areas for future research.

2.3 Identification of relevant literature

A comprehensive literature search was conducted on English-language articles published between 2015 and 2024. The search utilized seven major databases and scientific libraries: Scopus, ERIC (ProQuest), IEEE Xplore, ASEE peer, ScienceDirect, WILEY, and the ACM Digital Library. These were empirically justified based on their coverage, disciplinary focus, and indexing standards. This selection prioritizes databases specialized in higher engineering education, maximizing relevance and methodological diversity over generalist databases [12], [13], [14], [15]. However, WoS (Web of Science), due to its overlap with Scopus and its more selective indexing criteria, might exclude relevant conference proceedings and non-ISI journals. Therefore, empirical studies (e.g., Martín-Martín et al. [16]) confirm that Scopus includes nearly all WoS-indexed papers while also covering additional sources. Using Boolean operators, nine search terms were applied with keywords identified from the ScienceDirect and Education Resources Information Center (ERIC) databases. Further, 0 records found at ACM Digital Library. The search terms were refined through several test searches. The final search strategy was: ("Challenge-based learning" OR "CBL" OR "Challenge-driven Education") AND ("motivation" OR "student motivation") AND ("Engineering education" OR "Engineering") AND ("Higher Education" OR "Tertiary Education").

To enhance transparency and replicability, a PRISMA-style flowchart has been included in Figure 1, which visually represents the process of article selection, including the number of records identified, screened, and excluded at each stage [17].

2.4 Selection of relevant articles

The articles from the seven databases were manually exported into Microsoft Excel. Duplicates were removed, and the remaining studies were evaluated based on inclusion and exclusion criteria, as well as assessed for quality using specific questions. The quality of the final selected studies was evaluated using the Mixed Methods Appraisal Tool (MMAT) [18], which assesses studies based on methodological rigor, validity, and coherence, ensuring a standardized approach to quality assessment. This tool was chosen because of its applicability to diverse study designs, allowing for a more comprehensive evaluation of research among quantitative, qualitative, and mixed-method studies.

These criteria were applied to the titles and abstracts to ensure they effectively captured studies related to student motivation in CBL within higher engineering education. Two expert researchers reviewed the shortlisted articles, and decisions to accept or reject each article were made by consensus. In cases of disagreement between the reviewers, the article was independently reassessed by a third co-author with extensive experience in qualitative research. Discrepancies were resolved through iterative discussions to reach a final consensus. Criteria for selecting both abstracts and final articles were developed. Additional sources were identified by reviewing references from the selected studies and previous review articles. The exclusion criteria were established to maintain the relevance and specificity of the review. Studies focusing on PBL and PrBL were excluded because these methodologies, while student-centered, do not necessarily incorporate external stakeholder collaboration, a defining characteristic of CBL. Similarly, studies outside higher education (e.g., K-12 education or vocational training) were excluded to ensure that findings align with the scope of higher engineering education. Review articles, published theses, books, and editorials were omitted because they did not provide original empirical data relevant to the research questions. The inclusion and exclusion criteria, along with the quality assessment questions, are provided in Table 1.

Table 1. Inclusion and exclusion criteria

Criteria	Inclusion Criteria	Exclusion Criteria	Quality Principles
Criteria for study population	– Students, teachers, and external stakeholders in higher engineering education. – Education policymakers in higher engineering education. – Undergraduate, postgraduate, and PhD levels. – All genders and all races or ethnicities.	– Elementary, secondary, or upper-secondary education. – Adult or vocational education.	– Clearly articulated and justified research design aligned with research objectives and questions. – Sampling methodology must represent the target population.
Criteria for Phenomenon of Interest	– Challenge-Based Learning (CBL) in higher engineering education. – CBL with or without involvement of external stakeholders. – Student motivation in CBL. – Self-directed and self-regulated learning (SRL) in CBL.	– Studies focused on Problem-Based Learning (PBL) or Project-Based Learning (PrjBL).	– The selection of statistical techniques that align with the study's research design, data characteristics, and analytical objectives, contributing to the validity and reliability of findings, e.g., Descriptive statistics (to summarize motivation scores), inferential statistics (to compare motivation levels across student groups), regression analyses, structural equation modeling or path analysis (to examine complex relationships between motivation constructs), and qualitative data analysis techniques (thematic analysis, coding reliability measures, etc. when motivation is explored through open-ended responses). – Results/findings clearly presented and interpretable. – Ethical considerations are addressed.
Criteria for outcomes	– Studies reporting relevant outcome measures (e.g., CBL's impact on student motivation, content knowledge, and professional skills).	– Studies not reporting relevant outcome measures.	– Outcomes of the study that are measurable either qualitatively or quantitatively.
Criteria for research type	– Empirical studies using qualitative, quantitative, or mixed methods.	– Review articles, published theses, books, research reports, editorials, or letters.	

2.5 Data charting

The next phase of the study focused on organizing essential information from the primary research reports under review. This involved a process known as "charting" by Ritchie and Spencer [19], as referred to by Arksey and O'Malley [11]. Charting is a technique used to analyze and interpret qualitative data by systematically filtering, categorizing, and arranging content according to central issues and themes. This method aligns closely with our approach, so we have adopted the term for our use. The selected articles underwent thorough analysis, and critical data were systematically extracted to provide an objective synthesis of the review. The extracted information was organized in a tabular format, capturing details such as (i) the author(s) and publication year, (ii) the geographical context of the study, (iii) the research design and methodology employed, (iv) the participants involved, (v) the CBL approach implemented, and (vi) the primary outcomes observed.

2.6 Collating, summarizing, and reporting the results

This scoping study does not aim to synthesize evidence or consolidate findings across studies. Although it requires a thematic structure to narratively organize the literature, it does not evaluate the relative strength or quality of evidence supporting specific implementations. However, the use of the MMAT tool ensures that only methodologically sound studies are included, enhancing the credibility of the findings. By employing a consistent method of reporting results, it is possible to compare different types of implementations, identify conflicting evidence, highlight gaps, and consider new research areas [11].

The thematic analysis, grounded in Braun and Clarke's [20] approach, was conducted using NVivo software for qualitative analysis. The analysis followed a systematic process, beginning with a comprehensive reading of the selected articles to gain an in-depth understanding of the data. This initial stage facilitated the identification of key patterns inductively and elements relevant to the research questions deductively. The next step involved a detailed extraction of data, focusing on aspects related to CBL and its impact on student motivation. Relevant information was carefully identified and documented based on the inclusion criteria. Once extracted, these elements were analyzed and grouped into meaningful categories based on their conceptual or contextual similarities. In the subsequent stage, categories that conveyed similar underlying meanings were consolidated into broader themes, providing a coherent framework for interpreting the findings. Each theme was given an operational definition, which was refined through iterative discussions among the research team to ensure clarity and consistency. This process culminated in the final identification and naming of the key themes. Throughout the analysis, the themes and subthemes were presented to independent reviewers within the research team to ensure accuracy and consensus. Any disagreements were resolved through collaborative discussion, ensuring the reliability and robustness of the thematic framework used to address the research questions.

3 RESULTS

3.1 Literature search

A total of 374 articles were initially identified through the keyword search. After removing duplicates and non-original articles retrieved from various databases and resources, the abstracts of the remaining articles were screened according to the established inclusion and exclusion criteria. This process resulted in the assessment of 374 abstracts for eligibility. Articles that did not meet the criteria were excluded, narrowing the selection to 66 articles for a more detailed full-text review. These 66 articles were further evaluated based on the specific quality eligibility criteria (sample, concept of interest, study design, evaluation, and research type). Ultimately, 18 articles were deemed suitable and re-screened for the final review. The methodological process for the scoping review is depicted in Figure 1.

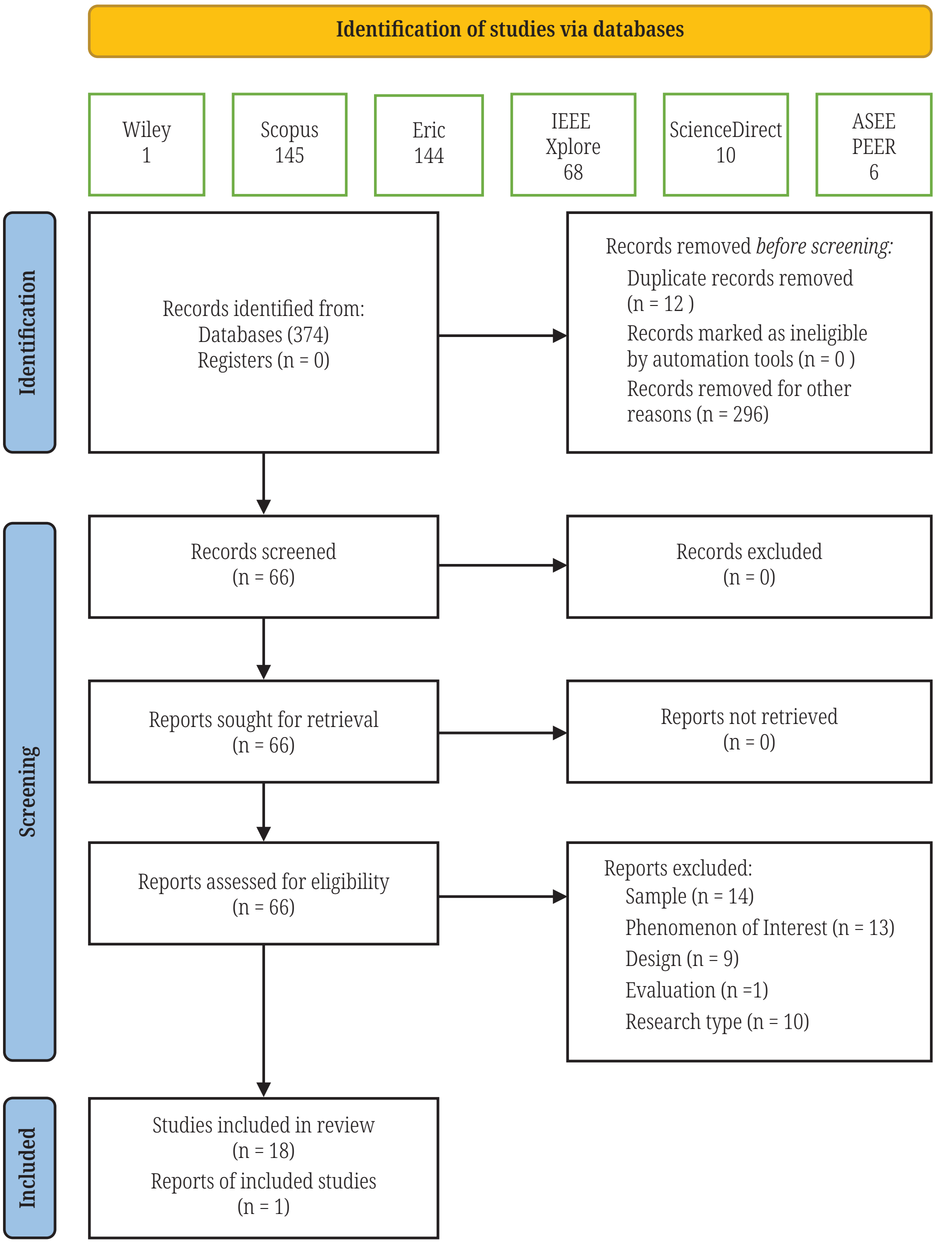

Fig. 1. The flow of literature search and article selection

3.2 Study characteristics

The final 18 articles were published between 2015 and 2024. Table 2 provides a clear geographical distribution of the selected studies, showing the dominance of

European and Latin American institutions in the research on CBL. This reflects a growing interest in CBL across both European and North American higher education, particularly within technical universities, where CBL is seen as a pedagogical approach for fostering active, authentic learning aligned with real-world engineering challenges.

Table 2. Geographical distribution of the selected studies

Country/Region	Number of Studies	Percentage of Total Studies	Institutions
The Netherlands	6	33.3%	TU Delft, TU Eindhoven, Wageningen University & Research, University of Twente, Eindhoven School of Education, Eindhoven University of Technology (TU/e)
Mexico	5	27.8%	Tecnológico de Monterrey
Spain	2	11.1%	Universidad Politécnica de Madrid (UPM)
Denmark	1	5.6%	Technical University of Denmark (DTU)
Sweden	1	5.6%	Royal Institute of Technology (KTH)
Germany	1	5.6%	University of Lübeck
USA	1	5.6%	University of Cincinnati, Ohio
Multi-country collaboration (Mexico, Netherlands, Ireland, China)	1	5.6%	TEC (Mexico), TU/e (Netherlands), DCU (Ireland), SJTU (China)

Predominantly, the studies employed quasi-experimental designs, utilizing quantitative methods such as surveys, self-report questionnaires, and inferential statistics (e.g., T-tests, factor analysis) to assess the outcomes of CBL. Additionally, several studies integrated mixed-methods approaches, incorporating qualitative data through interviews and reflective accounts to complement the quantitative findings and using different motivational theoretical frameworks for analyzing the data. This suggests a broad methodological consensus on the need for both quantitative rigor and qualitative depth in evaluating the multi-dimensional impacts of CBL on learning outcomes. Figure 2 presents the distribution of methods used in the final selected studies of the review.

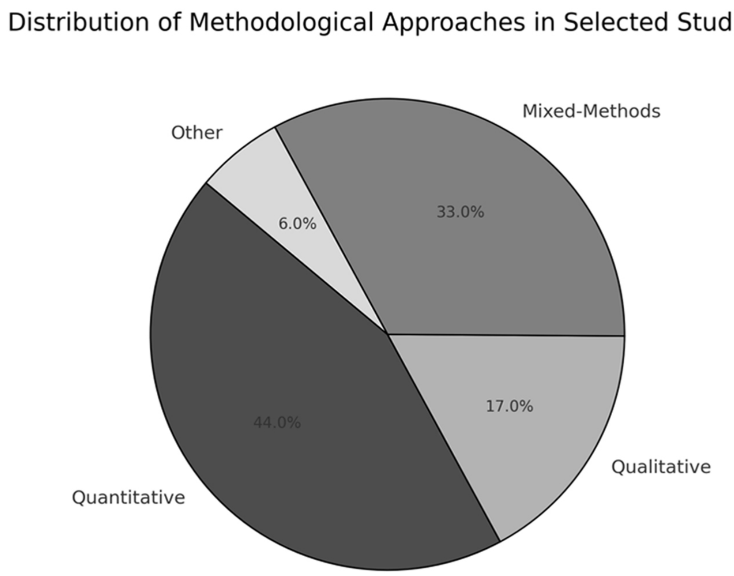

Fig. 2. Methodological approaches distribution (%)

The sample sizes varied widely, from small cohorts of 4–5 students to larger groups exceeding 200 students, with the majority focusing on undergraduate students in engineering and STEM disciplines, though a few studies included postgraduate participants. Such variation in sample sizes raises questions regarding the generalizability of the findings, particularly in smaller-scale studies where contextual factors may have a disproportionate influence on results.

CBL was implemented with an emphasis on solving real-world, interdisciplinary problems, often involving industry partnerships and external stakeholders. CBL was integrated into collaborative, cross-institutional courses across countries, leveraging remote communication tools, while other studies incorporated practical, hands-on projects that aimed to simulate professional engineering environments.

The studies consistently reported improvements in students' cognitive, affective, and psychological domains, with a particular emphasis on intrinsic motivation and self-determination. The Self-Determination Theory (SDT) framework was frequently utilized to assess motivational shifts, with many students reporting increased autonomy, competence, and relatedness—key tenets of SDT. Furthermore, studies highlighted the development of competencies such as critical thinking, problem-solving, and teamwork, which align with CBL's focus on preparing students for the demands of the globalized workforce. However, certain studies also noted challenges in sustaining interdisciplinary openness over time, indicating that while CBL promotes collaborative skills, there may be barriers to fully integrating interdisciplinary perspectives in complex engineering tasks. Figure 3 illustrates the key outcomes and challenges of selected studies.

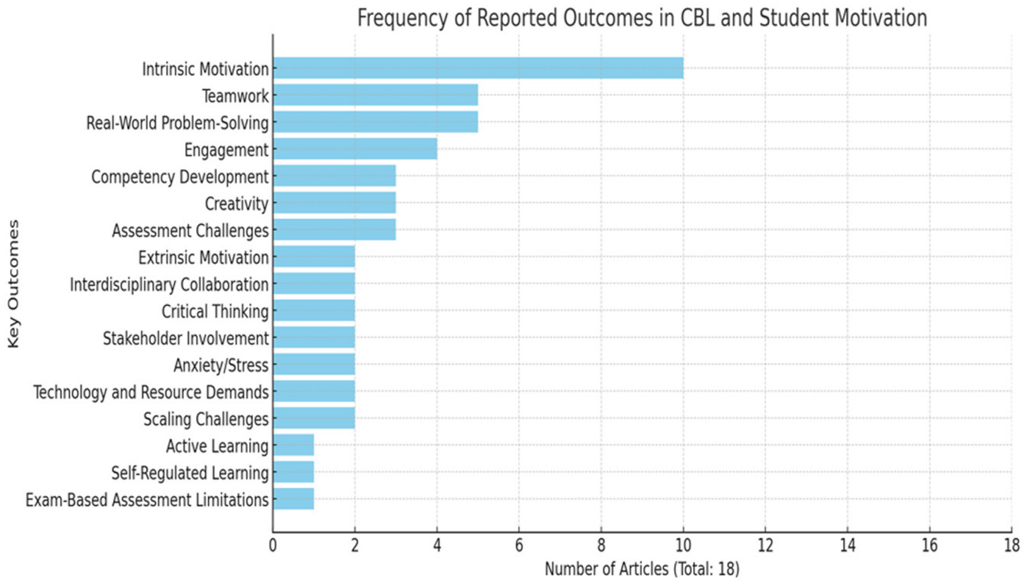

Fig. 3. Frequency of key outcomes and challenges in CBL and motivation

Across the studies, CBL was consistently linked to enhanced student motivation and engagement. The use of authentic assessment and the opportunity to apply theoretical knowledge in practical contexts were cited as key factors contributing to higher motivation levels. Nevertheless, as some studies highlight, the complexity of CBL projects can, in certain cases, lead to cognitive overload or reduced engagement, particularly when students face unclear objectives or excessive demands in terms of coordination and stakeholder involvement. Future research should focus on optimizing these pedagogical strategies to further enhance the impact of CBL on student learning outcomes and motivation. The information about the articles is summarized in Table 3.

Table 3. Studies characteristics

Author (Year)	Location	Study Design/ Method	Sample	Implementation	Outcome
Bohm et al. [21]	TU Delft and Wageningen University & Research (The Netherlands)	Motivational Letters	71 postgraduate students	Investigating students' arguments for why they wanted to take part in one of the challenges offered in two different CBL courses	Five distinct areas of reasoning that students utilize to enhance motivation: the content of the challenge, the qualities of the task, personal ambition, personal background, and teamwork
Bombaerts [22]	TU Eindhoven (The Netherlands)	Quasi-experimental design/exploratory studies; statistical analysis T-tests, Factor analysis; SDT; academic self-regulation questionnaire (SRQ-A)	30 students (1st study) 180 students (2nd study)	Evaluating CBL in Engineering Education by comparing student satisfaction, motivation, and engagement in humanities courses versus non-CBL courses, analyzing pilot and upscaled implementations	CBL enhances motivation among engineering students in humanities courses, evidenced by higher effort and intrinsic motivation. However, scaling poses challenges, such as diminished engagement and reduced support from stakeholders, potentially compromising the CBL's effectiveness
Caratozzolo et al. [23]	Tecnologico de Monterrey (Mexico) & Technical University of Denmark (Denmark)	Quasi-experimental design/Questionnaire; diagnostic tests; exit survey (VALUE Rubrics)	47 undergraduate students	CBL implementation by fostering international, remote collaboration between universities, allowing students to engage in collaborative, experiential "hands-on" activities through VPN technology, thus enhancing their problem-solving skills in a global context	Through CBL, development of competencies such as creativity, global citizenship, innovation, critical thinking, and interpersonal skills. International virtually collaboration enhanced enthusiasm, motivation, and intellectual engagement
Doulougeri et al. [24]	Eindhoven School of Education, TU Eindhoven (The Netherlands)	Mixed-methods sequential explanatory design/Survey (questionnaires) and semi-structured interviews	24 undergraduate engineering students (questionnaire) 16 undergraduate engineering students (interviews)	Students' experiences in a CBL course and exploration of personal and contextual factors that impacted their learning throughout the course	Students valued the real-world challenge and external-stakeholder involvement, which boosted engagement and motivation. Students found the course structure complex due to frequent meetings, multiple platforms, and divided assignments
Félix-Herrán et al. [25]	Tecnológico de Monterrey (Mexico)	Quasi-experimental design/ Mixed methods/ survey (13-item questionnaire 12 open-ended and one qualitative open question); field notes; assessment rubric	16 undergraduate engineering students	Implementation of an intensive CBL immersion where engineering students solve an unmanned aerial vehicle (UAV) challenge to develop disciplinary and transversal competencies within competency-based education (CBE)	CBL immersion with UAVs facilitated experiential learning, fostering collaborative skills, creative problem-solving, and self-directed skill acquisition. Students engaged deeply with complex tasks, enhancing intrinsic motivation and competency development

(Continued)

Table 3. Studies characteristics *(Continued)*

Author (Year)	Location	Study Design/ Method	Sample	Implementation	Outcome
Gaskins et al. [26]	University of Cincinnati, Ohio (USA)	Quasi-experimental design/Surveys; Questionnaire-open-ended/exam score	53 undergraduate students	CBL implementation in an engineering course to assess its impact on student learning experience	CBL fosters reflective, flexible thinking by situating learning in real-world problem-solving contexts, but its impact may be limited by traditional exam-based assessment methods
Herzog et al. [27]	University of Lübeck (Germany)	Proposal for designing CBL courses using Goodlad's curriculum typology	Non-required	Discussion study addresses practical aspects of designing and evaluating CBL courses in engineering ethics	Sustaining and institutionalizing the CBL concept, interactions and coordination and commitments foster students' motivation
Lazendic-Galloway et al. [28]	Eindhoven University of Technology (TU/e) (The Netherlands)	Case review/ mixed-methods; survey Questionnaires with closed & open questions	220 undergraduate and postgraduate students	The implementation of CBL at TU/e innovation Space, focusing on student experiences across 31 courses, emphasizing innovation, real-world challenges, and interdisciplinary collaboration	CBL courses enhanced students' interdisciplinary collaboration and motivation through real-world challenges, hands-on learning, and entrepreneurial skills, despite some issues with assessment clarity
López-Fernández et al. [29]	Universidad Politécnica de Madrid (Spain)	Motivational Diagnosis Instrument for Engineering Education (MDI-EE)/ 3 ad-hoc surveys	18 postgraduate students of Aerospace Engineering	Impact of CBL on the engineering students' motivation, on the professor-student relationship, and on the complete learning process	CBL boosted student motivation, enhancing intrinsic (achievement, self-confidence) and extrinsic (academic conditions, professor relationships) factors. Learning, technical skills, and professor-student communication improved, despite resource demands and initial student resistance
MacLeod et al. [30]	University of Twente (The Netherlands)	Quasi-experimental design/Surveys-9-item version of the intrinsic motivation inventory (Ryan & Deci, 2000)	17 students (courses 1&2 – 1st round) 7 students (course 1 – 2nd round) 12 students (course 2 – 2nd round)	CBL's influence on student motivation in two courses, examining how students' self-assigned roles in collaborative problem-solving align with their disciplinary expertise and affect motivational levels	CBL increased student motivation, as many valued skill development and addressing societal issues over strictly applying disciplinary expertise. However, some students still preferred disciplinary roles, and interdisciplinary openness slightly declined during the course
Merks et al. [31]	Eindhoven University of Technology (The Netherlands)	Quasi-experimental design/Survey; The 'Readiness for Online Learning Self-Efficacy' (ROLS) questionnaire (Hung et al., 2010)	32 undergraduate students (ROLS); 90 undergraduate students (course evaluation)	Evaluating Challenge-Based Modular on-demand Digital Education (CMODE) affects student learning and motivation in a bachelor Mechanical Engineering course	CBL didn't significantly increase online learning motivation or self-efficacy, however, CBL enhanced student engagement and focus. The improved challenge course plan and exam grades indicated better subject mastery

(Continued)

Table 3. Studies characteristics *(Continued)*

Author (Year)	Location	Study Design/ Method	Sample	Implementation	Outcome
Mora-Salinas et al. [32]	Tecnologico de Monterrey (Mexico)	Rubrics to assess students' achievement levels, allowing for structured evaluation of their outcome development in the CBL context	38 undergraduate students	CBL implementation through the i-Semester program, where engineering students tackle real-world automotive challenges with mentorship from university and industry experts	CBL enhanced student motivation and learning outcomes, as indicated by superior grades in practical challenges compared to traditional modules; nonetheless, challenges arose from scheduling conflicts, technological difficulties, and the necessity for enhanced evaluation tools
Olais-Govea et al. [33]	Tecnologico de Monterrey (Mexico)	Qualitative study/ Semi-structured interviews	4 undergraduate students	The development of transversal and soft skills in engineering students participating in the "Edumakers: Education for Inclusion" social service project using CBL approach	CBL enhanced motivation, active learning, and critical thinking, confirmed by ongoing projects in various development stages
Pantzos et al. [34]	Royal Institute of Technology (Sweden)	Pilot qualitative study/Semi-structured interviews/SDT	5 postgraduate students	SDT is used to explore motivational factors in CBL courses, focusing on students' needs for autonomy, competence, and relatedness	Motivations (e.g., innovation, societal impact, and thesis preparation) emerged, aligning with the SDT's continuum. Project choice, feedback, and group dynamics influenced students' psychological needs
Rodríguez-Chueca [35]	Universidad Politecnica de Madrid (Spain)	Quasi-experimental design/video-evaluation questionnaires (FC). Student questionnaire evaluation (CBL)	14 students (Environmental Management) 65 students (Industrial Ecology) 109 students (Environmental Engineering)	CBL and flipped-classroom implementation to enhance students' understanding of circular economy in STEM courses, focusing on diverse student groups with varying prior knowledge	CBL improved student motivation and competence acquisition, particularly in technical and transversal skills like teamwork and creativity. Students valued real-world applications, promoting a greater connection between them and the social and business reality
van den Beemt & MacLeod [36]	Eindhoven University of Technology (The Netherlands)	Evaluative case study/learning materials; semi-structured individual interviews; focus group interviews; surveys 9-item version of the intrinsic motivation inventory (Ryan & Deci, 2000), and the dimensions of social learning framework (Vrieling et al., 2016; Huijben et al., 2016); courses' evaluations	67 undergraduate students (questionnaires) 12–16 students each (focus groups interviews) 3 teachers and coaches (interviews)	Investigating support for interdisciplinarity, student engagement, and motivations in CBL-assignments of (TU/e) Innovation Space courses in engineering education	CBL promoted interdisciplinarity and student engagement but faced challenges in equitable discipline representation and assessment practices. Students demonstrated high motivation and anxiety due to complex tasks, indicating a need for clearer alignment of learning objectives while often prioritizing immediate problem-solving over collaborative learning outcomes

(Continued)

Table 3. Studies characteristics *(Continued)*

Author (Year)	Location	Study Design/ Method	Sample	Implementation	Outcome
van den Beemt et al. [4]	TEC (Mexico), TU/e (The Netherlands), DCU (Ireland), SJTU (China)	Exploratory comparative case study/policy documents, projects' evaluations, and non-structured interviews with faculty staff	Unknown number of informants	CBL implementation in higher education institutions in different contexts to contribute to developing skills and competencies	CBL enhances skills and innovation and promotes university-industry collaboration; however, it faces challenges in global scaling, resource demands, aligning technology with pedagogy, and adapting to diverse educational contexts. CBL enhances student motivation, self-regulated learning, and teamwork; however, high complexity and unclear learning objectives increase stress
Zavala et al. [37]	Tecnologico de Monterrey (Mexico)	Quasi-experimental design/ Questionnaire-MUSIC® model of Motivation	156 undergraduate students	Integration of Lean thinking into higher education through CBL, engaging students in real-world problem-solving to improve key performance indicators, with company collaboration and student motivation assessed through the MUSIC® model	CBL enhances student motivation in Lean Thinking through real-world problem-solving. Key outcomes include teamwork, empowerment, communication, and continuous feedback. Effective logistics and support from industry partners were crucial

4 FINDINGS

In this scoping review, we explore the effects of CBL on student motivation within the context of higher engineering education. CBL, an instructional approach that emphasizes real-world problem-solving and collaboration, has been recognized for its potential to foster intrinsic motivation, engagement, and professional development among students. This review synthesizes findings from 18 studies to identify key themes and subthemes related to how CBL influences student motivation. Through a thematic analysis, we aim to provide a comprehensive understanding of how CBL shapes students' motivational drivers, learning experiences, and professional identities, as well as the perceptions of teachers and stakeholders in these settings, answering the first research question. Table 4 presents the themes and subthemes derived from the reviewed studies.

Table 4. Themes and sub-themes of CBL on student motivation

Theme	Categories	Sub-Themes
CBL effects	Intrinsic & Extrinsic Motivation	– Intrinsic motivation – Extrinsic motivation
	Enjoyment & Engagement through Real-World Application	– Engagement and enjoyment
	Collaboration & Teamwork	– Team-based problem solving – Interdisciplinary collaboration
	Engineer Identity Formation	– Professional identity development – Limited real-world immersion
	Teacher's Role & Guidance	– Mentorship by teachers – Structured guidance
Student perceptions		– Relevance to professional development – Peer interaction and collaboration – Enhancing engagement and enjoyment – Self-regulated learning – Stress and work overload – Disparities in group work – Insufficient support and resources
Teacher perceptions		– Effective teaching methods
Stakeholder perceptions		– Positive industry feedback

4.1 CBL effects on student motivation

The analysis of the studies reveals that CBL positively impacts student motivation by fostering intrinsic and extrinsic motivation, encouraging engagement and enjoyment through real-world applications, and enhancing motivation through autonomy, collaboration, and teamwork. However, challenges remain, such as aligning academic goals with industry problems and fostering professional identity and teacher guidance, which can influence motivation negatively or in neutral ways.

Intrinsic and extrinsic motivation. The first theme that emerged centers around the dual nature of motivation in CBL settings—intrinsic and extrinsic. Among studies, intrinsic motivation was noted as a significant factor in driving students to engage with CBL. This form of motivation stems from internal rewards such as the sense of accomplishment, intellectual curiosity, and personal satisfaction that students derive from solving real-world problems. For example, López-Fernández et al. [29] reported that "Students exhibited high levels of intrinsic motivation due to engagement with real-world tasks." Similarly, MacLeod et al. [30] mentioned that "Overall student intrinsic motivation increased for each program rather than fell, likely as a response to students becoming more familiar with their challenges, their roles and their group members."

Extrinsic motivation, on the other hand, was often linked to future employment prospects and practical applications that push students to perform better in CBL. Doulougeri et al. [24] characteristically mentioned, "Students secured internships with industry partners, indicating increased motivation through career opportunities." Additionally, Pantzos et al. [34] noted that "a student who included a CBL course for his studies argued that it would be a good opportunity for doing a Master's thesis in the same company which collaborated with during the course." This extrinsic motivation was particularly notable in projects where students collaborated with industry, offering them direct exposure to potential employers and career opportunities.

Enjoyment and engagement through real-world application. Another prominent theme concerns engagement, which is closely tied to the real-world relevance of CBL. A recurring observation across the literature was that students are more motivated when they can see the direct application of their learning to real-world problems. Several studies [26], [34], [35] emphasized that students participating in CBL often feel more engaged because the tasks they are working on reflect the kinds of problems they will encounter in their future careers. The practical, hands-on nature of CBL helps bridge the gap between academic theory and professional practice, making learning more relevant and meaningful, "Engagement increased due to the connection of the course content to practical, real-world challenges" [26].

Van Den Beemt et al. [4] similarly noted that students reported higher enjoyment and engagement levels in CBL courses that incorporated real-world challenges, as these experiences were perceived to foster autonomy, social connection, and a sense of competence—key drivers of motivation according to SDT, "[…] students reported enjoying the challenges and the opportunity they offered them to engage with the industry."

However, the studies by Merks et al. [31] and Van Den Beemt & Macleod [36] noted that while real-world tasks engage students, difficulties in aligning academic knowledge content with industry problems occasionally lead to frustration and disengagement. Students felt that the learning objectives were unclear, resulting in lower motivation levels. Van Den Beemt & Macleod [36] concluded that "Motivation for working on challenges appeared high in this study. However, this was combined with anxiety for the challenge and stakeholders. The result could be that students develop a hands-on attitude, rather than a learning attitude, by focusing on the daily hassles of the project."

Collaboration and teamwork. Collaboration and teamwork are essential features of CBL, and the analysis reveals that these elements have a significant impact on student motivation. Interdisciplinary teamwork emerged as a critical factor, as it allowed students to engage with peers from different disciplines, contributing to a richer learning experience. Studies such as Zavala et al. [37] and Van Den Beemt & Macleod [36] found that students involved in interdisciplinary teams exhibited higher levels of motivation because they were able to share knowledge, solve complex problems together, and learn from each other's perspectives. "Team-based problem-solving fostered a collaborative environment that boosted motivation" [37].

Teamwork was particularly important for fostering a sense of belonging and mutual support, which in turn positively influenced motivation. Olais-Govea et al. [33] noted that students working in teams to develop educational solutions for children with visual disabilities experienced high levels of intrinsic motivation due to the collaborative problem-solving process, "one of the main internal forces that promoted the participation of students in the project was motivation, encouraged essentially by its social impact." Additionally, Caratozzolo et al. [23] found that through CBL and active learning approaches, "international virtually collaboration could be an effective strategy to train students with international skills and to develop certain personal attitudes such as enthusiasm, motivation, and intellectual engagement."

However, difficulties related to collaboration were also evident. Van Den Beemt & Macleod [36] pointed out that while interdisciplinary collaboration was encouraged, students were often guided by disciplinary frameworks, limiting their ability to freely explore diverse solutions. Moreover, some instructors reported difficulties in effectively facilitating and assessing interdisciplinary teamwork, which at times hindered students' motivation, "If interdisciplinary collaboration and integration are goals or expectations but all the tasks are geared just towards a limited set of fields, then this risks frustrating students who are not from business science. As such it appears more important that students have ownership of the problem/challenge and have control over it, and that this ownership is well supported and scaffolded" [36].

Engineer identity formation. One of the more nuanced themes that emerged pertains to the challenges students face in forming their professional identities within engineering education fields through CBL. While CBL offers the potential for students to develop their professional identities by working on real-world problems, several studies indicated that this process is not always straightforward. For example, Taconis & Bekker [38] found that while CBL fosters authentic STEM experiences, students often struggle to fully cultivate their professional identities due to the limited real-world immersion and pedagogical gaps in some CBL implementations, "CBL seems to fall short in creating "integrated" professional identities, possibly because the "immersion" in professional reality by CBL may be too limited." The study suggested that while CBL increases student motivation and confidence, it sometimes fails to provide sufficient depth in professional practice, which is critical for STEM identity formation. This lack of full immersion in real-world challenges can leave students feeling underprepared for their future careers, negatively impacting their motivation to pursue STEM disciplines long-term.

Teacher's role and guidance. The final theme relates to the evolving role of the teacher in CBL environments. In CBL, the teacher transitions from the traditional role of lecturer to that of a mentor or facilitator, guiding students through complex challenges. This shift has a direct impact on student motivation. Several studies, including Van Den Beemt et al. [4] and López-Fernández et al. [29], found that students responded positively to the mentorship aspect of CBL, as it allowed for more autonomy and personalized guidance, characteristically, "students valued their professors much better after working on the challenge side by side with them, and the student-professor relationship was closer and more productive…The learning process benefited from CBL…by the direct effect of boosting the students' motivation and improving the student-professor relationship" [29].

However, the mentoring role also places significant demands on teachers. Doulougeri et al. [24] noted that teachers struggled to align their teaching objectives with the real-world challenges presented in CBL, often requiring more time and effort to guide students effectively, which can negatively impact student motivation. In Doulougeri et al. [24], students claimed, "their difficulty dealing with uncertainty was the lack of propensity towards proactivity by actively seeking teachers' feedback and support." In conclusion, Doulougeri et al. [24] agreed that "Therefore, it is important that teachers communicate the goals and objectives of the course and the project to students so they have a better understanding of what is expected from them." Furthermore, Merks et al. [31] highlighted that without clear and consistent feedback from instructors, students might struggle to stay motivated throughout the course, particularly in modular, online, or hybrid CBL setups.

4.2 Perceptions of CBL in higher engineering education

Students' perceptions.

Relevance to professional development. Students found the CBL tasks relevant to real-world applications, enhancing the perceived value of their education. "The final consideration is the i-Semester favours the experience of professors and students in real industrial problems against the traditional classroom schemes" [32]. Engagement in CBL provided students with skills and experiences deemed valuable for their future professional careers."Students reported that the practical skills gained from CBL are directly applicable to their future engineering roles" [34]. Finally, in López-Fernández et al. [29] study, students mentioned that "The Challenge will be useful for my future career."

Peer interaction and collaboration. In the study by Gaskins et al. [26], one of the key themes identified by students in a CBL environment was the "interactive" nature of the classroom, which they appreciated the most. This indicates that a student-centered approach fosters better student-teacher engagement and highlights that students place a high value on opportunities for interaction with their instructors during class. CBL students argued that "interaction was one of the best features of the class" [26].

Students also demonstrated a strong preference for challenges related to sustainability and collaboration, seeing them as opportunities to make a meaningful impact on society. "Considering the different types of stakeholders (e.g., visitors, the municipality, energy providers), I would like to be able to work together with them and to have a role in maintaining this contact between all these different parties" [21].

Enhancing engagement and enjoyment. Students showed high levels of engagement because the CBL approach actively involved students in the learning process, promoting deep understanding and sustained attention. "Most students find CBL to be a highly engaging learning method" [34]. The enjoyment derived from participating in CBL was evident, contributing positively to motivation."I enjoyed taking part in this Concurrent Engineering session as a challenge and interacting with the three other groups of students" [29].

Self-regulated learning. Students felt a sense of intellectual growth and responsibility through participation in CBL. "The intrinsic motivators related to the sense of accomplishment and internal recognition (3.88, 3.82, and 3.58), the advancement feeling (3.47), the sense of intellectual growth (3.17), and the sense of responsibility (3.41 and 3.23) were also very high" [29].

Stress and work overload. The challenging nature of CBL sometimes led to increased stress among students. "Some students reported feeling stressed due to the high demands of the CBL projects" [4]. Students also experienced work overload due to the intensive nature of CBL activities. "Students felt that the workload in CBL was significantly higher compared to traditional courses" [37].

Disparities in group work. Issues of unequal participation within groups were noted, affecting overall student motivation. "The disparity in contribution levels among group members was a significant concern" [34]. Additionally, group dynamics sometimes led to conflicts, negatively impacting the motivational levels of students. "Some students found group work challenging due to differing levels of commitment among members" [24].

Insufficient support and resources. Insufficient guidance and support from teachers affected the success of CBL initiatives. "The lack of timely and constructive feedback from teachers was a significant drawback" [4]. Furthermore, the lack of sufficient resources for CBL activities was a recurring issue. "The shortage of necessary tools and equipment hindered the smooth execution of CBL tasks" [36].

Teachers' perceptions.

Effective learning methods. Teachers recognized the benefits of CBL as an effective and active learning method in fostering student motivation and engagement. Felix-Harran et al. [25] mentioned that "The teachers evaluated that this behavior demonstrated a certain level of motivation and collaborative effort." Additionally, Gaskins et al. [26] also mentioned the teachers' perceptions, pointing out that

"Along with caring, students felt that the teachers were enthusiastic about what they were teaching."

Stakeholders' perceptions.

Positive industry feedback. Industry partners noted the practical and instructional benefits of CBL, "The participation of the training partner in the evaluation of transversal competencies enriched the feedback process to the students" [32], as well as the professional preparation provided by CBL, "A prospect for stakeholders to continue relations is viewing CBL courses as a pool for future talent" [27].

In addressing the second research question, this scoping review examines the diverse educational and methodological approaches employed to study the impact of CBL on student learning and motivation in higher engineering education. Various research methods, including quantitative, qualitative, and mixed approaches, have been utilized to evaluate CBL's effectiveness. Additionally, motivational theories and tools have been applied to both qualitatively and quantitatively measure changes in student motivation. This thematic analysis identifies the key research methods, motivational frameworks, and the implications of these findings, shedding light on the practical and theoretical advancements in CBL. Table 5 presents the themes and subthemes derived from the studies analyzed.

Table 5. Themes and sub-themes of CBL research methods, motivational frameworks, and implications

Theme	Categories	Sub-Themes
Research approaches		– Quantitative methods – Qualitative methods – Mixed methods approach
Motivation assessment	Quantitatively	– Academic Self-Regulation Questionnaire (SRQ-A) – 9-item version of the Intrinsic Motivation Inventory – Motivational Diagnosis Instrument for Engineering Education (MDI-EE)
	Qualitatively	– MUSIC® model of Motivation – Readiness for Online Learning Self-Efficacy (ROLS) questionnaire – Self-Determination Theory (SDT)
Implications and improvements		– Real-world problems relevance and instrudry collaboration – Active learning methods – Reforming assessment methods – Enhancing teacher proficiency in CBL

4.3 Research approaches used in CBL studies

The studies presented in Table 5 utilize various methods to investigate CBL and its impact on student motivation in higher engineering education. The predominant research methods include quasi-experimental designs, often paired with questionnaires, interviews, diagnostic tests, and semi-structured interviews. These methods allow researchers to assess quantitative and qualitative student experiences and outcomes.

Many studies, such as those by Félix-Herrán et al. [25], Bombaerts [22], Gaskins et al. [26] and others as seen in Table 4, rely on quasi-experimental design, which involves pre-existing groups rather than random assignment. This method is coupled with tools like questionnaires and interviews to collect data on student perceptions, motivation, and performance. For example, Bombaerts [22] found higher intrinsic motivation and effort in CBL courses compared to traditional ones. Similarly, Mora-Salinas et al. [32] observed high levels of engagement, with students actively participating in topics beyond the curriculum.

Some studies, like Doulougeri et al. [24], employ a mixed-methods sequential explanatory design, combining both quantitative surveys and qualitative interviews. This approach provides a deeper understanding of both the statistical outcomes and the underlying reasons for student responses. For example, Doulougeri et al. [24] and Zavala et al. [37] found that students valued the practical nature of tasks and the involvement of real-world clients, which boosted their intrinsic motivation and made the learning more applicable to their future careers.

Finally, Caratozzolo et al. [23] and Mora-Salinas et al. [32] use diagnostic tests, essays, and presentations as part of their assessment methods, evaluating improvements in creativity, innovation, critical thinking, and subject matter competence.

Evidence on the long-term impact of CBL on student motivation and retention in engineering education is still developing, but several studies have offered insights into how CBL influences students over time. Gaskins et al. [26] observed that CBL fosters long-term engagement in STEM fields by increasing students' positive perceptions of their abilities and performance in complex tasks. Lazendic-Galloway [28] noted that the real-life challenges and the active participation of external stakeholders increased students' interest and fostered intrinsic motivation, which can persist even after the course ends.

While direct evidence of CBL's long-term impact on student retention is less frequently quantified, several studies suggest that students who participate in CBL are more likely to continue their engineering education. For example, Zavala et al. [37] found that students involved in CBL programs, such as the Kaizen i-Semester, were more engaged and often pursued additional internships or job opportunities directly related to their training. This suggests that CBL can have a positive influence on retention by providing career-relevant skills and real-world experiences.

However, Van den Beemt & MacLeod [36] and Merks et al. [31] pointed out difficulties in integrating interdisciplinary learning and aligning online and in-person components of CBL. These challenges may affect the consistency of long-term motivation and retention, particularly when students encounter poorly coordinated learning environments. Finally, Taconis & Bekker [38] argued that while there is strong potential for CBL to boost long-term motivation and engagement, empirical evidence of its long-term effects is still limited, particularly in terms of data on retention rates over multiple years.

4.4 Motivation assessement in CBL

Several studies in this scoping review have utilized quantitative tools and motivational theories to assess student motivation. This section reviews key studies that employed such methods, highlighting how motivation was measured and its impact on student learning.

One notable example is the study by Bombaerts [22], which applied SDT and used the Academic Self-Regulation Questionnaire (SRQ-A). This quasi-experimental design aimed to assess motivation and engagement among engineering students in both humanities and non-CBL courses. The results showed that CBL enhanced intrinsic motivation and effort, particularly in courses integrating interdisciplinary elements, while highlighting challenges such as reduced engagement in scaled implementations.

Caratozzolo et al. [23] employed a quasi-experimental design involving questionnaires and diagnostic tests to measure motivation. The findings indicated that CBL fostered enthusiasm, motivation, and intellectual engagement through hands-on, collaborative problem-solving activities.

MacLeod et al. [30] also utilized a quantitative approach, specifically the 9-item version of the Intrinsic Motivation Inventory by Ryan and Deci [39], to assess motivation. The results showed that while CBL increased motivation, some students preferred to apply their disciplinary expertise over interdisciplinary engagement, suggesting a tension between role preferences and the open, collaborative nature of CBL. Similarly, van den Beemt and MacLeod [36] also used the 9-item version of the Intrinsic Motivation Inventory [39] to investigate interdisciplinarity and student engagement in CBL courses at Eindhoven University of Technology. The study demonstrated that CBL promoted student motivation, though it also increased stress due to the complexity of tasks and unclear learning objectives.

López-Fernández et al.'s [29] study used the Motivational Diagnosis Instrument for Engineering Education (MDI-EE) and three ad-hoc surveys to explore the motivational effects of CBL on engineering students. Students reported increased self-confidence and achievement, alongside enhanced relationships with professors. Despite these benefits, challenges included resource demands and initial student resistance to CBL methodologies.

Merks et al. [31] employed the Readiness for Online Learning Self-Efficacy (ROLS) questionnaire to evaluate the effects of CBL on student motivation and learning in a Mechanical Engineering course at Eindhoven University of Technology. The study found that while CBL did not significantly increase online learning motivation or self-efficacy, it enhanced student engagement and focus, leading to improved subject mastery.

Pantzos et al. [34] used the SDT as a theoretical lens to explore motivational factors among postgraduate students. This pilot study examined how CBL aligned with students' needs for autonomy, competence, and relatedness, key components of SDT. The study found that project choice, group dynamics, and feedback were crucial in meeting these psychological needs, which in turn fostered intrinsic motivation and engagement.

Lastly, Zavala et al. [37] employed the MUSIC® model of motivation to assess student motivation during a CBL course on Lean Thinking at Tecnológico de Monterrey. The MUSIC® model was particularly effective in identifying motivational outcomes such as empowerment, communication, and continuous feedback, all of which contributed to sustained student motivation throughout the course.

4.5 Implications and improvements of CBL

The findings show that CBL teachers and external stakeholders consistently recommend practices that integrate real-world problems, active learning, and stakeholder involvement to enhance student motivation. In addition, calls for reformed assessment methods and greater teacher proficiency suggest that CBL can be made more effective by creating environments where students feel engaged, supported, and prepared for real-world challenges in engineering.

Real-world problems relevance and industry collaboration. Mora-Salinas et al. [32] and Herzog et al. [27] emphasise the importance of integrating real-world problems and involving industry partners in CBL. This real-world connection makes the learning process more meaningful and motivating for students and prepares them for the challenges they will face in professional environments. Mora-Salinas et al. [32] demonstrated that "The final consideration is the i-Semester favours the experience of professors and students in real industrial problems against the traditional classroom schemes." Herzog et al. [27] further suggest that stakeholder engagement creates a dynamic ecosystem that boosts student motivation, "Ideally, a successful consideration of student output by a stakeholder is openly and communicated to the students, lecturers and even higher-level university representatives. Such communication could be institutionalised by establishing a CBL course-specific "landing page" that features news and project results."

Active learning methods. Bombaerts [22] and López-Fernández et al. [29] both highlight the necessity of continuing to use active learning methods to sustain high levels of engagement. Active learning, where students are directly involved in the learning process through activities such as group work, discussions, and problem-solving, helps maintain their interest. López-Fernández et al. [29] explicitly state that "Moreover, the involved students had already experienced active learning methods during their studies, and it contributed to boost their motivation." Bombaerts [22] also suggests expanding the use of CBL into broader contexts, including humanities courses in higher engineering education, to encourage cross-disciplinary learning that might further engage students with diverse interests, "We conclude that CBL can be a motivating approach for humanities in Engineering Education. CBL can be scalable but "small-scale strengths" can be lost with gradual scaling."

Reforming assessment methods. Gaskins et al. [26] argue, "Since students are conditioned to judge their success based on exam performance, the impact of CBL could be limited unless the process by which student performance for course grade is re-examined." Instead of focusing on exams, the shift should be toward assessments that emphasize learning and process rather than grades. By doing so, students can focus on solving real-world challenges and developing competencies, which can foster intrinsic motivation.

Enhancing teacher proficiency in CBL. Teachers also need to enhance their skills in implementing CBL, especially in guiding students to incorporate disciplinary knowledge into interdisciplinary challenges. Van den Beemt & MacLeod [36] highlight that "teachers appear in need of competence development especially on assessing integration and integrating discipline knowledge, and on supporting students in integration and synthesis," so more training in this area is essential for assisting students effectively, particularly when navigating complex, real-world problems, and fostering student motivation.

5 DISCUSSION

This discussion delves deeply into the impact of CBL on student motivation, interdisciplinary engagement, and pedagogical practices, based on both the scoping review and recent findings in higher education literature. Drawing on contemporary research and theoretical frameworks, this analysis addresses the critical role of CBL in developing competencies, fostering student-centered learning, and enhancing engagement through real-world problem-solving. CBL's alignment with modern pedagogical shifts—such as constructivist, experiential, and active learning models—positions it as a transformative educational approach, especially in higher engineering education.

A primary focus of the scoping review was understanding how CBL impacts student motivation in higher engineering education. CBL's emphasis on engaging students in real-world problems supports the development of both intrinsic and extrinsic motivation, which are crucial components for fostering learning [40]. Intrinsic motivation refers to students' internal drive to engage in activities out of interest and personal satisfaction, which CBL facilitates by offering autonomy, problem-solving, and relevance to students' interests. As numerous studies within the scoping review and recent literature affirm, CBL fosters a strong sense of ownership and mastery in students, enhancing their motivation to tackle complex engineering problems. The SDT, often employed in educational research, highlights that autonomy and competence—two core aspects of CBL—are critical to sustaining students' intrinsic motivation [4], [40]. However, CBL also effectively taps into extrinsic motivation, particularly through the involvement of external stakeholders such as industry partners and relevance to students' future careers. This connection to real-world applications provides external incentives—such as career opportunities and networking—that drive students to perform at higher levels [41]. Extrinsic rewards, particularly when tied to professional success and industry recognition, further validate the relevance of CBL in engineering education. In this context, the expectancy-value theory becomes relevant, as students are more likely to engage in learning activities when they perceive their efforts will lead to meaningful outcomes, such as professional growth or employment opportunities [42].

CBL fosters interdisciplinary learning by engaging students in cross-disciplinary teamwork to tackle real-world challenges. In higher engineering education, this approach enhances student motivation, teamwork, problem-solving, and ethical reasoning skills, preparing them for collaborative professional environments. Research suggests that cross-disciplinary projects enable students to integrate diverse knowledge and perspectives, improving their problem-solving abilities and adaptability. While these projects enhance motivation and readiness for real-world challenges, further research is needed to examine their long-term impact and broader skill development [43], [44]. The scoping review identified several studies showing that interdisciplinary teamwork enhances critical thinking, communication, and collaboration—all skills critical for professional engineers [43], [45]. From a pedagogical standpoint, this integration of disciplines aligns with constructivist learning theories, where students build knowledge through active engagement with complex, authentic tasks [46], [47], [48]. Constructivist approaches, particularly in the context of PBL and PrBL, share similarities with CBL in terms of student-centeredness and the focus on real-world problems [9]. However, what sets CBL apart is its stakeholder involvement, which not only provides authentic challenges but also external validation, feedback, and implementation of social interactions, further enriching the students' learning experience and motivation [49]. Nonetheless, interdisciplinary learning within CBL poses challenges, including resistance from students with traditional engineering backgrounds and the need to accommodate diverse learning motivations. Tackling these challenges involves developing advanced epistemological beliefs and critical thinking skills through interdisciplinary learning, leading to improved academic performance and therefore motivation [50]. Several studies, including those in the scoping review, highlighted difficulties in sustaining interdisciplinary openness over time, with students sometimes falling back into their disciplinary comfort zones. This issue points to the need for scaffolding within CBL environments to ensure that students maintain interdisciplinary perspectives and do not retreat to familiar disciplinary boundaries when faced with complexity [31].

Vygotsky's theory of the Zone of Proximal Development (ZPD) is particularly relevant here, as it emphasizes the importance of teacher and peer support in helping students reach beyond their current abilities [51]. Effective scaffolding strategies, such as guided collaboration and structured reflection, can help students navigate the complexities of interdisciplinary work, thereby enhancing their overall learning outcomes [9].

The methodologies used to assess CBL's effectiveness have evolved, with an increasing reliance on mixed-methods approaches that integrate quantitative and qualitative data to capture the complexity of learning in CBL environments. However, the scoping review revealed key differences in how their methods capture CBL's impact on motivation.

Quantitative studies often employ surveys, diagnostic tests, and quasi-experimental designs to measure motivation, engagement, and learning outcomes [24], [52]. These studies frequently report positive effects on motivation, citing increased student engagement, improved performance, and higher satisfaction with CBL, however, many rely on self-reported data, raising concerns about response biases. Only a few studies explicitly employed established motivation theories, such as SDT, to frame their findings on student motivation. Specifically, for example, Caratozzolo et al. [23], focus on describing the observed effects on motivation (e.g., enhanced engagement, performance) without anchoring these findings in established motivation theories. This creates a gap in understanding the psychological mechanisms behind how and why CBL fosters motivation. Many studies, such as van den Beemt et al. [4] and Rodríguez-Chueca [35], offer valuable empirical data on increased student motivation and engagement but do not use motivational theories to interpret these findings. This lack of theoretical discussion restricts the ability to generalize the findings across different educational contexts or explain how certain motivational factors might vary. Furthermore, several studies rely on descriptive accounts from student questionnaires and interviews, highlighting positive outcomes, such as improved engagement and real-world application, but missing opportunities to explain these through the lens of motivation theories. This is evident in studies, such as López-Fernández et al. [29] and Mora-Salinas et al. [32]. Without grounding in established motivation theories, the findings are harder to generalize or replicate across different educational settings. Theoretical frameworks provide a roadmap for understanding which components of CBL (e.g., autonomy, competence, relatedness) drive motivation and why. Further, the absence of motivational frameworks limits deeper exploration into how different types of motivation (e.g., intrinsic vs. extrinsic, short-term vs. long-term motivation) are influenced by CBL.

Recent literature on CBL highlights the importance of developing authentic assessment practices that align with the pedagogical goals of CBL. Traditional assessments, such as exams, may not fully capture the competencies developed in CBL environments, where process-oriented skills—such as teamwork, critical thinking, and problem-solving—are paramount [26]. Therefore, alternative assessment methods, such as portfolios, peer evaluations, and reflective essays, are recommended to provide a more comprehensive evaluation of student performance [45].

Moreover, the effectiveness of CBL is contingent on the teacher's role as a facilitator, rather than a lecturer. Teachers in CBL environments must adopt a more constructivist role, guiding students through complex challenges without providing direct solutions. This shift necessitates significant professional and pedagogical development for educators, as managing interdisciplinary teams and coordinating with external stakeholders requires specific skills [41]. In line with transformational leadership theories and pedagogy, teachers in CBL settings must inspire and motivate students by fostering an environment of collaboration and innovation, enabling students to take ownership of their learning [53], [54], [55], [56].

While CBL offers numerous advantages in fostering student motivation and interdisciplinary learning, it also presents several challenges that warrant further investigation. Qualitative studies provided richer insights into students' experiences, uncovering psychological, social, and contextual factors influencing motivation. One of the most prominent issues identified in the scoping review is cognitive overload, where students may become overwhelmed by the complexity and scope of CBL projects. This issue often arises when students are faced with ill-defined problems and insufficient guidance, leading to frustration and disengagement [31], thwarting students' psychological needs and decreasing motivation for studying and learning [34], [57]. Future research should explore strategies to mitigate cognitive overload, such as incremental learning and modular project design, which can break down complex challenges into more manageable tasks [48], [58]. Technological tools can further aid in this process. Cognitive scaffolding, through digital platforms that manage project complexities, helps break down tasks and allows students to concentrate on solving specific parts of a challenge at a time. Galdames-Calderón et al. [41] noted that integrating technology with modular designs in CBL not only enhances learning but also minimizes the risk of cognitive overload by ensuring students have access to clear, structured guidance throughout the learning process. Furthermore, the long-term impact of CBL on student retention and professional development remains underexplored. While short-term gains in motivation and engagement are well-documented, there is limited empirical data on the sustainability of these effects beyond the duration of the course. Longitudinal studies that track students' progress over several years, both academically and professionally, are needed to assess the long-term benefits of CBL in engineering education [41].

6 LIMITATIONS OF THE STUDY

This scoping review focused on capturing recent research on student motivation in CBL contexts within higher engineering education. To achieve this, literature published before 2015 was excluded. While earlier publications undoubtedly hold value, the decision to limit the timeframe was guided by Okoli and Schabram's [59] assertion regarding the inherent challenges of comprehensively retrieving all relevant articles during a literature search. Consequently, this review concentrated on studies published between 2015 and 2024, an approach aligned with the concept of study maturity as discussed by Chigbu et al. [60] and Kraus et al. [61]. According to these authors, a maturing research field often yields a higher volume of publications that explore diverse aspects of its core topics. This timeframe also coincides with Malmqvist et al.'s [8] foundational work, which provides a clearer delineation of CBL as a pedagogical approach in higher engineering education. Within this period, a substantial number of studies addressing the enhancement of student motivation in engineering through CBL were identified.

However, a notable limitation of this review is the exclusion of studies focused on the initial phases of the COVID-19 pandemic, which began at the end of 2019. This period marked a significant shift in educational practices, with many institutions rapidly transitioning to online learning environments. As a result, this review may have overlooked insights into specific learning behaviours and strategies critical for implementing CBL during this unique context.

Interestingly, the review did identify studies that explored online CBL sessions conducted during the pandemic. These studies highlighted the role of digital proficiency as an additional functional skill fostered through CBL. Despite the transition to virtual formats, no significant changes in student motivation were observed, suggesting that CBL's core principles remained effective even in the face of pandemic-related disruptions.

The study selection process involved manually exporting articles from seven databases, which may introduce selection bias. However, multiple reviewers applied standardized inclusion criteria to ensure reliability. The review also relied on the MMAT for quality assessment, but this tool may not fully capture all potential biases in certain study designs.

It is important to clarify that the limited presence of qualitative studies in this review was not due to selection bias by the authors but rather a result of the available literature. The findings indicate a lack of qualitative research exploring CBL's effect on student motivation in higher engineering education. This highlights a gap in the existing research rather than a methodological shortcoming of our study.

7 CONCLUSIONS

This scoping review investigated the effects of CBL on student motivation in higher engineering education and examined the methodological approaches used to study these effects. The findings highlight CBL's potential as a transformative educational approach, fostering intrinsic and extrinsic motivation, engagement, and professional skill development through real-world problem-solving and interdisciplinary collaboration. CBL bridges the gap between academic knowledge and industry practice, equipping students with both technical skills and cross-cutting competencies essential for addressing complex local and global challenges.

7.1 Summary of key findings

The review identified three major themes in how CBL influences student motivation: (i) its role in enhancing intrinsic and extrinsic motivation by fostering autonomy, competence, and real-world relevance [62], (ii) its effectiveness in promoting interdisciplinary collaboration and teamwork [63], and (iii) the need for structured support to mitigate challenges such as cognitive overload and disengagement [48]. While CBL generally has positive effects, the findings suggest that these benefits are dependent on course design, teacher facilitation, and appropriate scaffolding mechanisms.

7.2 Future research

Despite its strengths, the review identifies areas for further study. A critical gap remains in the lack of longitudinal studies assessing the long-term effects of CBL on student motivation and professional development. Future research should track students over multiple years to determine how CBL influences career choices, persistence in engineering, and long-term skill retention. The study by Johnson et al. [64] provides foundational insights into these aspects, but more recent and extensive research is needed. Additionally, given the predominance of quantitative methodologies, qualitative research—such as in-depth case studies and ethnographic approaches—should be prioritized to explore students' lived experiences and the psychological mechanisms behind motivation [20].

Moreover, it is essential to examine the impact of CBL in diverse educational settings, including non-English-speaking contexts. Cultural and linguistic factors can significantly influence student motivation and engagement. For instance, Doulougeri et al. [65] highlight that implementing CBL in non-English-speaking countries requires careful consideration of language barriers and cultural differences to ensure effective learning outcomes.

7.3 Practical implications for higher engineering education

These findings have significant implications for syllabus designers, education developers and educators aiming to implement CBL effectively in higher engineering education. First, structured scaffolding techniques—such as guided collaboration, modular project design, and continuous feedback—are essential to sustaining student motivation and preventing cognitive overload [48]. Second, interdisciplinary teamwork should be carefully designed to ensure equitable participation across disciplines, mitigating issues where students revert to their disciplinary comfort zones. Third, authentic assessment methods, including portfolios, peer evaluations, and reflective essays, should be integrated to better capture the competencies developed in CBL environments [63]. Lastly, faculty training programs should be developed to equip educators with the necessary skills to facilitate CBL effectively, particularly in managing industry collaborations and balancing student autonomy with instructional support [66], [67], [68].

Finally, this scoping review reinforces CBL as a student-centered approach that aligns education with the demands of the modern world. By addressing identified gaps, enhancing teacher training, and refining implementation strategies, educators and institutions can harness the full potential of CBL, ensuring its effectiveness in motivating and preparing the next generation of engineers. Based on the findings from this study, and since we do not have studies outside Europe and North America, the findings have brought to the fore the need to contextualise the ideas and practices of CBL within these contexts to help students develop a holistic view of learning in higher engineering education.

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