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Massive Open Online Courses for Engineering Education: Systematic Literature Review

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Abstract

This systematic literature review synthesizes recent empirical research on the implementation of Massive Open Online Courses (MOOCs) in engineering education published between 2020 and 2024. Following PRISMA 2020 guidelines, ten high-quality studies indexed in ERIC and Scopus were systematically identified, appraised, and analyzed. The review addresses four research questions concerning research methodologies, instructional models, learning outcomes, learner populations, and implementation challenges. The findings indicate that MOOCs are most effective when embedded within integrated pedagogical systems rather than implemented as standalone online courses. Three complementary instructional approaches blended learning, virtual laboratories, and immersive or metaverse-based environments emerge as key mechanisms for supporting higher-order cognitive processes, practical engineering competencies, learner self-efficacy, engagement, and persistence. However, persistent challenges, including high dropout rates, limited hands-on experiences, and contextual constraints, highlight the importance of alignment between instructional design, learner characteristics, and technological infrastructure. The primary contribution of this study is the development of a theoretically grounded conceptual framework that integrates structural, experiential, and contextual dimensions of MOOC-based learning in engineering education. This framework advances current understanding beyond descriptive synthesis by providing an explanatory foundation for instructional design, institutional implementation, and future research on scalable and context-responsive engineering learning environments.

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Introduction

The landscape of higher education has undergone a profound transformation in the 21st century, driven by rapid technological advancement and the increasing demand for accessible, flexible learning opportunities (Bonk et al., 2015; Siemens et al., 2015). Among the most disruptive innovations in this transformation are Massive Open Online Courses (MOOCs), which have emerged as scalable platforms capable of democratizing access to knowledge and expanding participation in higher education across geographical and socioeconomic boundaries (Kaplan & Haenlein, 2016; Reich & Ruipérez-Valiente, 2019). Since their emergence in 2008 and rapid expansion during what has been termed "The Year of the MOOC" in 2012, MOOCs have significantly challenged traditional instructional paradigms and institutional structures (Pappano, 2012; Veletsianos & Shepherdson, 2016).

Engineering education, as a discipline characterized by its strong emphasis on applied knowledge, problem-solving, and hands-on experimentation, presents a particularly complex context for the integration of MOOCs (Alario-Hoyos et al., 2017; Gamage et al., 2020). Traditional engineering pedagogy relies heavily on laboratory-based learning, collaborative design, and iterative practice, which are difficult to replicate in fully online environments (Jona & Narayanan, 2018; Marques et al., 2014). Nevertheless, recent technological advancements, including virtual laboratories, simulation-based environments, and hybrid learning models, have enabled new forms of pedagogical integration that extend beyond the limitations of early MOOC implementations (De Jong et al., 2013; Potkonjak et al., 2016).

Despite the rapid proliferation of MOOCs and their increasing adoption in engineering education, the existing body of research remains fragmented and largely descriptive. Previous reviews have either focused broadly on MOOCs across disciplines or examined isolated dimensions of engineering MOOCs without providing a comprehensive synthesis of instructional, methodological, and contextual factors (Bozkurt et al., 2017; Deng et al., 2019; Khalil & Ebner, 2014; Yousef et al., 2014). Furthermore, the accelerated adoption of online learning technologies during the COVID-19 pandemic has introduced new pedagogical configurations and challenges that necessitate a re-examination of recent empirical evidence (Dhawan, 2020; Mishra et al., 2020). These developments highlight the need for a theoretically grounded synthesis that moves beyond descriptive categorization toward explanatory understanding.

From a theoretical perspective, the integration of MOOCs into engineering education can be conceptualized through multiple complementary lenses, including constructivist learning theory, experiential learning, and technology-enhanced learning frameworks (Bates, 2015; Laurillard, 2013). These perspectives emphasize the importance of aligning instructional design, learner interaction, and technological affordances with disciplinary learning outcomes. However, the extent to which current MOOC implementations in engineering education reflect such theoretical alignment remains insufficiently examined. Specifically, there is a lack of systematic analysis linking research methodologies, instructional models, learner populations, and implementation contexts to broader theoretical and practical implications (Freeman et al., 2014; Ruiz et al., 2006).

However, we argue that existing studies have not sufficiently conceptualized MOOCs in engineering education as integrated pedagogical systems. Instead, they remain fragmented across methodological, instructional, and contextual dimensions. This lack of integration limits the field's ability to generate transferable theoretical insights and scalable instructional models. Therefore, a synthesis that explicitly connects these dimensions is required.

To address these gaps, the present systematic literature review synthesizes recent empirical studies published between 2020 and 2024, focusing on MOOCs in engineering education. By systematically examining research methodologies, instructional approaches, learning outcomes, target populations, and implementation challenges, this study aims to provide a theoretically informed and empirically grounded understanding of how MOOCs are being designed, implemented, and evaluated in contemporary engineering education contexts. In doing so, the review contributes to advancing both theoretical knowledge and practical applications, offering a foundation for future research, instructional design, and policy development in technology-enhanced engineering education.

Research Questions

This systematic literature review is guided by four research questions that are theoretically and empirically grounded to advance understanding of MOOCs in engineering education:

RQ1: What research methodologies have been employed in recent studies examining MOOCs in engineering education?

This question is critical for evaluating the epistemological foundations of the field. By identifying dominant methodological approaches (e.g., experimental, mixed-methods, design-based research), this review assesses the maturity of research and the extent to which current studies support causal inference, contextual understanding, and theory development. Understanding methodological trends enables the identification of gaps in research rigor and informs future methodological advancements.

RQ2: What instructional methods are utilized in engineering MOOCs, and what learning outcomes have been reported?

This question addresses the pedagogical core of MOOC implementation. It is theoretically grounded in constructivist and experiential learning perspectives, which emphasize the alignment between instructional design and learning outcomes. By examining how different instructional models (e.g., blended learning, virtual laboratories, immersive environments) influence cognitive, affective, and skill-based outcomes, this question contributes to understanding the effectiveness and pedagogical validity of MOOCs in engineering contexts.

RQ3: What populations are primarily served by engineering MOOCs?

This question is essential for understanding the demographic and contextual scope of MOOCs. From an equity and access perspective, MOOCs are intended to democratize education; however, their actual reach and effectiveness across different learner groups (e.g., undergraduate students, professionals) remain uneven. This question provides insight into participation patterns and informs the design of inclusive and context-sensitive MOOC environments.

RQ4: What are the main challenges and advantages associated with implementing MOOCs in engineering education?

This question focuses on the practical and institutional dimensions of MOOC integration. It is grounded in technology adoption and implementation frameworks, highlighting the interaction between technological affordances, pedagogical design, and contextual constraints. Identifying challenges (e.g., dropout rates, resource limitations) and advantages (e.g., scalability, flexibility) contributes to developing actionable strategies for sustainable and effective implementation.

Together, these research questions are designed not only to map the current state of research but to generate an integrated understanding that supports theoretical advancement and practical innovation in engineering MOOCs.

Significance of the Study

This systematic literature review makes several significant contributions to the field of engineering education and technology-enhanced learning.

First, the study provides a theoretically informed synthesis of recent empirical evidence, advancing understanding beyond descriptive summaries toward an integrated conceptual perspective. By linking research methodologies, instructional models, and learning outcomes to established theoretical frameworks, the study contributes to the development of a more coherent knowledge base in engineering MOOCs.

Second, the study offers practical implications for educators, instructional designers, and policymakers. By identifying effective instructional strategies, such as blended learning and virtual laboratories, as well as common implementation challenges, the findings support evidence-based decision-making in curriculum design and institutional planning (Borrego et al., 2013; Streveler & Smith, 2006).

Third, the study contributes to methodological advancement by critically examining the research designs employed in the field. Insights from RQ1 highlight strengths and limitations in current research practices, providing guidance for future studies seeking to enhance rigor, validity, and theoretical contribution (Zawacki-Richter et al., 2018).

Finally, by addressing issues of access, participation, and implementation (RQ3 and RQ4), the study contributes to the broader discourse on educational equity and innovation. The findings support the development of scalable, inclusive, and contextually relevant MOOC models that align with the evolving demands of engineering education and the global workforce (Margaryan et al., 2015; Onah et al., 2014; Christensen et al., 2013; Peters & Jandric, 2015).

Method

This systematic literature review was conducted using a transparent and reproducible protocol aligned with the

PRISMA 2020 reporting framework. The review procedures were designed to minimize selection bias and enhance methodological rigor through independent screening, standardized extraction, formal quality appraisal, and explicit reliability checks across reviewers. The review focused on peer-reviewed journal articles examining Massive Open Online Courses (MOOCs) in engineering education published between 2020 and 2024.

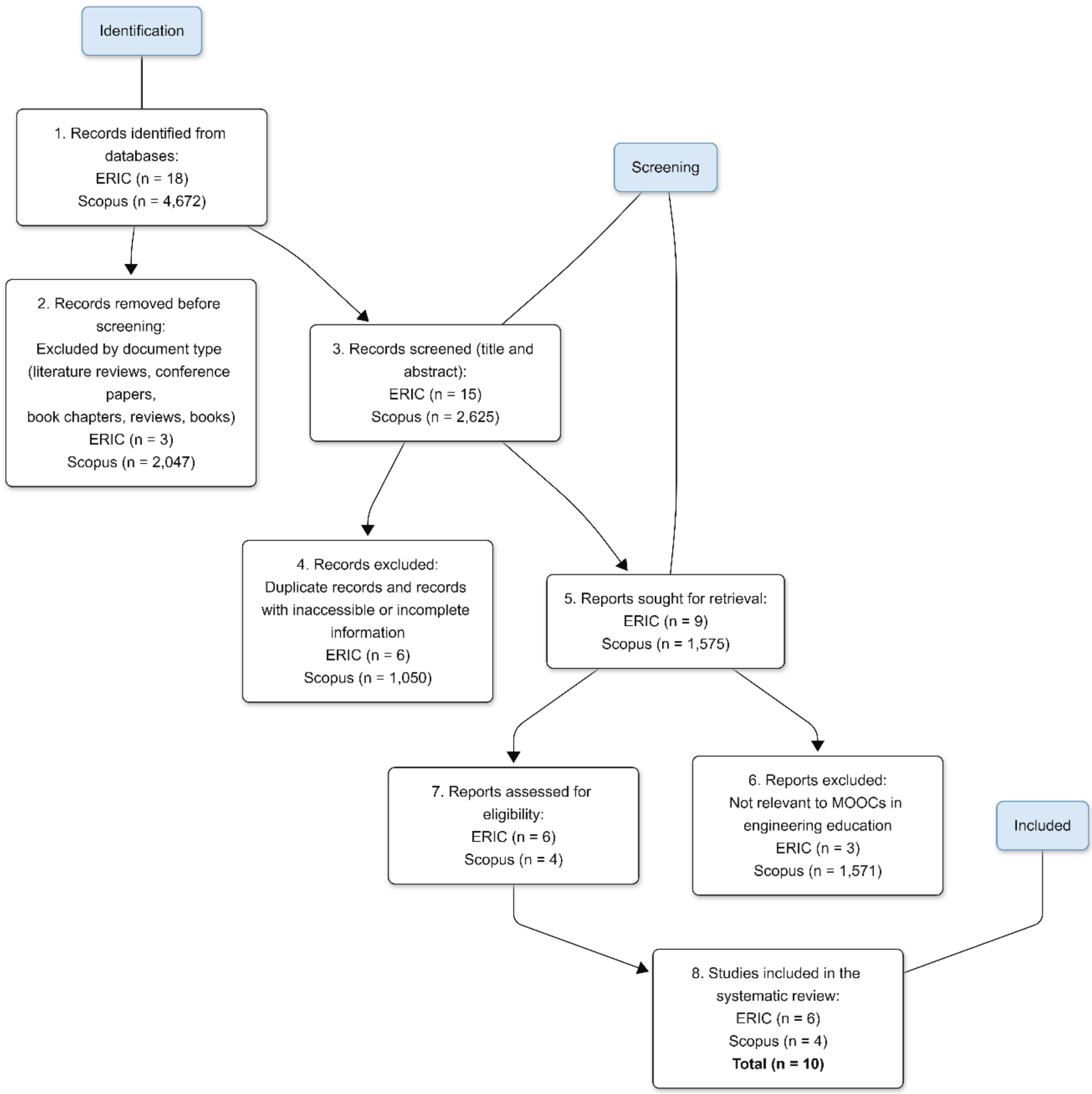

Figure 1. Result of Article Search Using PRISMA 2020

Figure 1. PRISMA 2020 flow diagram of the study selection process. The figure presents the identification, screening, eligibility assessment, and inclusion of studies retrieved from ERIC and Scopus databases. Ten studies met all inclusion and quality criteria and were included in the final review.

Search Strategy and Information Sources

A systematic search strategy was developed to identify relevant studies across two databases with complementary coverage: ERIC, selected for its comprehensive indexing of education research, and Scopus, selected for broad multidisciplinary coverage including engineering and educational technology. Searches were limited to the publication period 2020–2024 to capture the most recent evidence, including post-pandemic developments in online and blended engineering education. Database searches were conducted using Boolean combinations of keywords representing the two conceptual domains of interest (MOOCs and engineering education), and search syntax was tailored to each database to ensure consistent retrieval across platforms.

Table 1. Keywords and Their Derivatives in Journal Article Searches

Main Keywords	Derivative Keywords
Massive Open Online Courses	Massive Open Online Courses = MOOCs, MOOCs education
Engineering Education	Engineering education = Engineering learning

Table 2. Search Journal Articles by Keyword

Database	Search keywords
ERIC	"MOOCs" AND "engineering education"
Scopus	"MOOCs" AND "engineering education"

Eligibility Criteria

Explicit inclusion and exclusion criteria were established prior to screening. Studies were included if they (a) investigated MOOCs or MOOC-related formats implemented in engineering education contexts, (b) were published as peer-reviewed journal articles indexed in ERIC or Scopus, (c) were published between 2020 and 2024, and (d) reported sufficient methodological information to enable appraisal and extraction. Studies were excluded if full text could not be accessed, if they were duplicates, if they were not primary empirical research (e.g., literature reviews, conference papers, books, or book chapters), or if MOOCs were not substantively implemented or evaluated within an engineering education context.

Table 3. Inclusion and Exclusion Criteria

Inclusion Criteria	Exclusion Criteria
Journal articles on the topic of learning from MOOCs in engineering education	Journal articles that cannot be accessed
	Duplicate journal articles (previously found)
Journal articles that were published on ERIC, Scopus	Journal articles that are not complete (not full text)
Journal articles published in 2020 – 2024	Journal articles in the form of literature reviews, Conference paper, Book chapter, Review, Book

Study Selection Procedure

Study selection followed four sequential stages consistent with PRISMA: identification, screening, eligibility assessment, and inclusion. Records retrieved from ERIC and Scopus were exported and deduplicated prior to screening. Title-and-abstract screening was then conducted independently by two reviewers using the pre-specified eligibility criteria. Records judged potentially eligible proceeded to full-text review, which was also performed separately by the same reviewers. Disagreements at any stage were resolved through discussion; when consensus could not be reached, a third reviewer adjudicated. To reduce drift in screening decisions, the review team conducted a calibration exercise before formal screening, jointly applying the criteria to a subset of records and refining decision rules until consistent interpretations were achieved.

Data Extraction

A standardized extraction form was developed and piloted to ensure consistent capture of study characteristics and outcomes relevant to the review questions. Extracted fields included bibliographic information, study design and methodology, instructional approach and MOOC format, learning outcomes and measurement methods, population and sample characteristics, context (e.g., country/region and educational level), and reported implementation factors (challenges, advantages, and disadvantages). Data extraction was conducted independently by two reviewers for all included studies. Following independent extraction, entries were cross-checked and reconciled to ensure accuracy, completeness, and consistent coding of constructs across studies.

Data Analysis and Synthesis

The review used a combination of descriptive and thematic analytic techniques. Descriptive analyses were used to summarize methodological patterns, instructional approaches, and sample characteristics across the included studies. A thematic analysis approach was applied to synthesize qualitative and mixed-evidence findings related to instructional methods, learning outcomes, and implementation factors. Themes were developed iteratively through repeated comparison across studies and refined to ensure conceptual clarity and non-overlap. The final narrative synthesis was structured by the four research questions, enabling the integration of evidence across diverse research designs while preserving contextual specificity.

Quality Appraisal Rubric and Study Quality Classification

To strengthen evidentiary confidence, all included studies were appraised using a structured quality rubric developed for this review to accommodate diverse research designs (quantitative, qualitative, mixed-methods, experimental, and development/evaluation studies). The rubric comprised eight methodological domains: clarity of aims and research questions; appropriateness of study design; adequacy of sampling and participant description; rigor of data collection procedures; transparency and rigor of data analysis; validity/trustworthiness strategies (e.g., triangulation, instrument evidence, credibility procedures); coherence of results and conclusions; and disclosure of limitations and potential sources of bias. Each domain was rated on a three-point scale (0 = not addressed/unclear, 1 = partially addressed, 2 = clearly addressed with adequate detail), yielding a total score range of 0–16. Studies were classified as high quality (13–16), moderate quality (9–12), or lower quality (0–8). Only studies meeting at least the moderate threshold were retained for synthesis, and appraisal outcomes were used to contextualize the strength of claims in the narrative synthesis rather than serving solely as exclusionary evidence. A summary of rubric scoring decisions was retained as an audit trail to support transparency and reproducibility.

Table 4. Quality Appraisal Rubric for Studies Included in the Systematic Review

No.	Quality Domain	Score = 0	Score = 1	Score = 2
1	Clarity of Research Aims and Questions	Research aims or questions are unclear, implicit, or not stated	Research aims/questions are stated but lack precision or alignment with the study	Research aims/questions are clearly stated, specific, and well aligned with the study design
2	Appropriateness of Research Design	Research design is inappropriate or not justified in relation to the aims	Research design is generally appropriate but justification is limited	Research design is clearly appropriate and well justified for addressing the research aims
3	Sampling and Participant Description	Sampling strategy or participant characteristics are absent or poorly described	Basic information on sampling or participants is provided but lacks detail	Sampling strategy and participant characteristics are clearly described and appropriate
4	Rigor of Data Collection Procedures	Data collection methods are unclear, weak, or insufficiently described	Data collection procedures are described but lack detail or rigor	Data collection procedures are clearly described, systematic, and appropriate
5	Rigor and Transparency of Data Analysis	Data analysis methods are unclear, inappropriate, or inadequately reported	Data analysis methods are generally appropriate but lack transparency or depth	Data analysis methods are clearly described, systematic, and analytically rigorous
6	Validity / Trustworthiness Strategies	No strategies to ensure validity, reliability, or trustworthiness are reported	Limited strategies are reported (e.g., basic instrument checks or credibility claims)	Appropriate strategies are clearly reported (e.g., triangulation, validation, reliability, credibility)
7	Coherence of Results and Conclusions	Conclusions are weak, unsupported, or inconsistent with results	Conclusions are generally supported but lack depth or critical interpretation	Conclusions are well supported, coherent, and logically derived from the results
8	Reporting of Limitations and Bias	Study limitations or potential biases are not acknowledged	Some limitations are mentioned but superficially discussed	Limitations and potential sources of bias are clearly acknowledged and critically discussed

All included studies were appraised using an eight-domain quality rubric designed to accommodate diverse empirical research designs. Each domain was rated on a three-point scale (0–2), yielding a maximum score of 16. Studies were classified as high, moderate, or lower quality based on total scores. Quality appraisal results were used to contextualize the strength and credibility of the findings in the synthesis rather than serving as the sole exclusion criterion.

Table 5. Mapping: Quality Rubric

Rubric Score	Visual Judgment	Colors
2	High	🟢
1	Moderate	🟡
0	Low	🔴

Table 6. Quality Appraisal Matrix of Included Studies

Study	D1	D2	D3	D4	D5	D6	D7	D8	Overall Quality
P1 Pertuz et al. (2023)	🟢	🟢	🟡	🟢	🟡	🟡	🟢	🟡	🟡 Moderate
P2 Phan (2023)	🟢	🟢	🟢	🟢	🟢	🟡	🟢	🟡	🟢 High
P3 Medina-Labrador et al. (2023)	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟡	🟢 High
P4 Chen (2022)	🟢	🟢	🟢	🟢	🟢	🟡	🟢	🟡	🟢 High
P5 Wengrowicz et al. (2023)	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟡	🟢 High
P6 Prates et al. (2023)	🟢	🟢	🟡	🟢	🟢	🟡	🟢	🟡	🟢 High
P7 Guan et al. (2021)	🟢	🟢	🟡	🟢	🟢	🟡	🟢	🟡	🟢 High
P8 Zhang et al. (2023)	🟢	🟢	🟡	🟢	🟢	🟢	🟢	🟡	🟢 High
P9 AlMunifi & Aleryani (2023)	🟢	🟢	🟢	🟡	🟡	🟢	🟢	🟡	🟢 High
P10 Roldán-Álvarez et al. (2024)	🟢	🟢	🟡	🟢	🟡	🟢	🟢	🟡	🟢 High

Domain Legend

D1: Clarity of research aims and questions

D2: Appropriateness of research design

D3: Sampling and participant description

D4: Rigor of data collection

D5: Rigor and transparency of data analysis

D6: Validity / trustworthiness strategies

D7: Coherence of results and conclusions

D8: Reporting of limitations and bias

All included studies were appraised using the eight-domain quality rubric. Total scores ranged from 12 to 15, indicating that all studies met at least a moderate level of methodological quality, with the majority classified as high quality. Quality appraisal results were used to contextualize the strength of evidence in the synthesis rather than serving as exclusion criteria.

Inter-Rater Reliability and Disagreement Resolution

To ensure reliability in study selection, extraction, and quality appraisal, inter-rater agreement was quantified at key stages. During title-and-abstract screening and full-text eligibility assessment, agreement was assessed using Cohen's kappa alongside percentage agreement to provide both chance-corrected and intuitive indicators of consistency. The same reliability approach was applied to a randomly selected subset of extracted fields and to rubric ratings to confirm consistent interpretation of extraction codes and appraisal criteria. Discrepancies were resolved through structured reconciliation meetings in which reviewers compared decision rationales against the protocol; unresolved cases were referred to a third reviewer for final determination. This reliability-first workflow was implemented to reduce subjective bias and increase the defensibility of conclusions drawn from heterogeneous evidence.

Results

The systematic literature review followed the PRISMA 2020 guidelines, leading to the inclusion of 10 peer-reviewed journal articles that met all predefined eligibility and quality criteria. The selected studies collectively provide a robust evidence base for examining the implementation of MOOCs in engineering education across diverse instructional models, learner populations, and technological contexts.

Research Methodological Characteristics of Included Studies

The reviewed studies demonstrate not only methodological diversity but also reveal an emerging epistemological transition in MOOC research within engineering education. While quantitative and experimental designs dominate studies focusing on measurable outcomes such as academic performance, self-efficacy, and dropout rates, this pattern reflects a broader emphasis on validation-oriented research rather than theory development. We argue that this methodological tendency indicates a field still in a transitional phase, where empirical validation is prioritized over explanatory modeling. Although experimental and quantitative approaches provide robust evidence of effectiveness, they often fail to capture the contextual and pedagogical complexities inherent in engineering MOOCs. In contrast, the increasing adoption of mixed-methods approaches suggests a growing recognition of the need to integrate statistical rigor with contextual understanding.

Furthermore, development and evaluation studies, particularly those focusing on virtual laboratories and immersive learning environments, signal a shift toward design-oriented research paradigms. These approaches are not merely evaluating learning outcomes but actively addressing discipline-specific instructional challenges. This trend suggests that the field is gradually moving toward solution-driven inquiry, where technological innovation and pedagogical design are co-evolving.

Taken together, these findings imply that future research should move beyond isolated methodological approaches and adopt integrative designs that simultaneously support causal inference, contextual interpretation, and theoretical advancement.

Table 7. Summary of Quality Appraisal Scores of Included Studies (n = 10)

ID	Author Name	Types of Research
P1.	Said Pertuz , Oscar Reyes, Elio San Cristobal , Russell Meier , and Manuel Castro	The study adopts a design-based empirical case study to evaluate the implementation of a MOOC-Based Flipped (MBF) classroom in undergraduate engineering education, integrating qualitative and quantitative evidence to examine pedagogical alignment, instructional workload, and learning outcomes.
P2.	Nga Thi Tuyet Phan	The research employs a mixed-methods design, integrating quantitative and qualitative data to enhance the robustness of the findings.
P3.	Manuel Medina-Labbrador, Gustavo Rene Garcia-Vargas, Fernando Marroquin-Ciendua	The research is primarily experimental, utilizing a 2x2x2 factorial design to analyze dropout behavior in MOOCs, focusing on the effects of 'Peanut effect' bias, gamification, and monetary compensations.
P4.	Cheng-Hu Chen	The research is quantitative in nature, focusing on measuring changes in self-efficacy levels among engineering students before and after attending a blended MOOC on English Technical Writing skills.
P5.	Niva Wengrowicz, Rea Lavi, Hanan Kohen Dov Dori	The research employs a mixed-methods approach, combining both quantitative and qualitative data collection and analysis.
P6.	Jorge Marques Prates, Silvana Morita Melo, Pedro Henrique Dias Valle, Rogério Eduardo Garcia, José Carlos Maldonado.	The research is experimental in nature, focusing on the application of Small Private Online Courses (SPOCs) in Software Testing education.
P7.	Shouping Guan, Gairan Zgao, Shubin Tan and Lin Xu	The research focuses on the development and evaluation of a virtual online laboratory for teaching control systems (CCS) in an educational context.
P8.	Kang Zhang, Zhijing Shao, Yun Lu, Ying Yu, Wei Sun, and Zeyu Wang	The research focuses on the development and evaluation of a Metaverse-driven Massive Open Online Course (MOOC) environment, referred to as MOMC, which integrates immersive technologies such as volumetric video and virtual reality.
P9.	Abdullatif A. AlMunifi, Arwa Y. Aleryani	The research is primarily qualitative in nature, focusing on the motivations, challenges, and interactions of MENA professionals attending online courses in technology and engineering.
P10.	David Roldán-Álvarez, José M. Cañas, David Valladares, Pedro Arias-Perez and Sakshay Mahna	The research is focused on the development and validation of Unibotics, an open online learning platform designed for practical learning in robotics education.

Instructional Models and Learning Outcomes in MOOCs for Engineering Education

Table 8 synthesizes instructional methods and corresponding learning outcomes across the included studies. Three dominant instructional models emerged: blended learning, virtual laboratory–supported MOOCs, and immersive or metaverse-based MOOCs. These models represent progressively deeper levels of pedagogical integration and learner engagement.

Blended Learning as a Structural Integration Mechanism

Blended learning, particularly the MOOC-Based Flipped (MBF) classroom, emerges as a dominant instructional model across the reviewed studies. However, rather than functioning merely as a combination of online and face-to-face modalities, we argue that blended learning operates as a structural integration mechanism that resolves inherent limitations of standalone MOOCs. Specifically, blended learning redistributes instructional roles by shifting content delivery to asynchronous environments while reserving synchronous or face-to-face interactions for higher-order cognitive processes such as problem-solving and application. This redistribution aligns with constructivist and experiential learning principles, enabling learners to engage more deeply with engineering concepts. This finding suggests that the effectiveness of MOOCs is not determined by the platform itself but by the extent to which it is embedded within a structured pedagogical system. Therefore, MOOCs should be conceptualized as components of integrated learning architectures rather than independent instructional solutions.

Virtual Laboratories as Experiential Learning Enablers

Virtual laboratories represent a critical mechanism for addressing one of the most persistent challenges in engineering education: the development of practical skills in online environments. The reviewed studies consistently indicate that virtual laboratories enhance conceptual understanding, procedural competence, and learner engagement. We contend that the effectiveness of virtual laboratories lies in their ability to operationalize experiential learning in digital environments. By enabling repeated experimentation, immediate feedback, and learner-controlled pacing, these tools simulate key aspects of hands-on engineering practice. However, their effectiveness is not intrinsic to the technology itself but depends on their integration with instructional guidance and assessment strategies. This suggests that virtual laboratories should not be viewed as substitutes for physical labs, but as pedagogical mediators that extend and transform experiential learning. Their role is to bridge the gap between theoretical knowledge and practical application, particularly in resource-constrained or fully online contexts.

Immersive and Metaverse-Based MOOCs as Engagement Amplifiers

Immersive and metaverse-based MOOCs represent an emerging frontier characterized by the integration of virtual reality and volumetric technologies. The reviewed studies indicate that these environments significantly enhance learner engagement by fostering presence, emotional involvement, and embodied interaction. We argue that immersive MOOCs function as engagement amplifiers, particularly in domains requiring spatial reasoning and system visualization, which are central to engineering education. By creating environments where learners can interact with complex systems in a simulated space, these technologies extend beyond traditional cognitive learning toward embodied cognition. However, the findings also reveal that their effectiveness is constrained by technological infrastructure, accessibility, and instructional alignment. This suggests that while immersive MOOCs offer high pedagogical potential, their scalability depends on contextual factors such as institutional readiness and resource availability.

Table 8. The Method and Learning Outcome of MOOC Learning for Engineering Education

ID	Method	Learning Outcome
P1.	The research paper discusses integrating MOOCs into on-campus courses through a model known as the MBF (MOOC-Based Flipped) classroom. This model emphasizes a structured design that promotes interaction and relevance between online and on-campus activities, aligning them with intended learning outcomes.	The course's learning outcomes were designed to align with Bloom's taxonomy, focusing on the cognitive complexity levels of remembering, understanding, applying, analyzing, evaluating, and creating.
P2.	The research employed a mixed-methods design to enhance data robustness by combining quantitative and qualitative sources.	The research indicates that engineering students in Taiwan and Vietnam exhibit moderate self-efficacy in MOOC environments, particularly in independent learning, with the highest ratings in self-efficacy for independent learning and the lowest in English self-efficacy.
P3.	The research employed a quantitative methodology with a longitudinal non-experimental study design.	The research highlights those cognitive biases, specifically the 'Peanut effect,' along with gamification and monetary compensation, can significantly reduce dropout rates in MOOCs.
P4.	The study utilized a sample of 122 students, comprising 113 full-time undergraduates and 9 part-time graduate students, with ages ranging from 19 to 35 years.	The study found that students exhibited a significant increase in self-efficacy after participating in a blended MOOC on English Technical Writing skills. This improvement in self-efficacy was positively correlated with academic performance, indicating that students with higher self-efficacy levels achieved better course grades.
P5.	The research employed a mixed-methods approach, combining quantitative and qualitative data collection and analysis. Quantitative data included	The learning outcomes associated with the MORTIF component include enhanced learner engagement through active learning

ID	Method	Learning Outcome
	responses from an online questionnaire with close-ended questions, while qualitative data was derived from open-ended questions in the same questionnaire.	and meaningful feedback. Students reported significant improvements in understanding concepts due to the immediate feedback provided after submissions, which allowed them to identify and correct mistakes effectively.
P6.	The research employed a controlled experiment to evaluate the effectiveness of a SPOC in teaching software testing during emergency remote education due to the COVID-19 pandemic.	The study's learning outcomes indicate that students participating in the SPOC demonstrated improved performance and motivation compared to those in traditional education settings.
P7.	The method uses a virtual online laboratory built with virtualization technology, allowing students to perform experiments flexibly and conveniently.	The learning outcomes from the virtual laboratory indicate that it effectively enhances students' interest in learning and their comprehensive understanding of control systems.
P8.	The methodology involves creating a digital 3-D stereoscopic space of a lecture hall, allowing digital twins of lecturers and students to engage in interactive activities. This is achieved through volumetric video technology, which captures realistic human movements and expressions, enhancing emotional interaction in the learning environment. The MOMC framework integrates metaverse technology into traditional MOOC settings, utilizing VRAR capabilities to improve retention and engagement. The approach also includes the use of various accessibility devices, enabling immersive learning experiences that promote knowledge internalization and exploration. This methodology aims to overcome the limitations of traditional MOOC environments.	The research highlights that the integration of volumetric video technology within the MOMC framework significantly enhances learning outcomes by providing a realistic and immersive educational experience.
P9.	The research employed a survey to explore the multidimensional impact of online technology and engineering courses on professionals in the MENA region.	The learning outcomes of online technology and engineering courses primarily include enhancing knowledge previously acquired and developing practical skills necessary for professional advancement. Many participants reported gaining tangible achievements, such as job promotions or new job opportunities,

ID	Method	Learning Outcome
		after completing these courses. However, some expressed frustration over a lack of significant change in their professional status. The courses also aimed to compensate for learning loss in formal education, focusing on providing a well-structured environment for lifelong learning and skill enhancement. However, the effectiveness of these outcomes was hindered by inadequate practical components and lack of recognized certifications.
P10.	The Unibotics methodology involves providing an open online learning platform for robotics education, allowing users to edit and run robot programs directly in their browsers.	The primary learning outcome of the Unibotics platform is to enhance the practical skills of robotics engineering students through hands-on programming and simulation exercises.

Population Characteristics and Contextual Diversity

The reviewed studies encompass a diverse range of learner populations, including undergraduate and graduate students as well as working professionals. While this diversity enhances the generalizability of findings, it also reveals important contextual dependencies in MOOC effectiveness. We argue that MOOCs do not function as universally effective learning environments but are highly sensitive to learner characteristics and contextual conditions. For example, variations in language proficiency, digital literacy, and institutional support significantly influence learning outcomes and engagement levels. This finding challenges the assumption that MOOCs inherently democratize education. Instead, it suggests that access alone is insufficient; effective participation requires alignment between learner readiness, instructional design, and technological infrastructure.

Table 9. Population and Sample in Journal Articles

ID	Population	Sample
P1.	The research paper does not provide specific information about the study's population. However, it mentions that the designed course took place with 23 students enrolled, focusing on a third-year Electronics Engineering course at Universidad Industrial de Santander. The course lasted 16 weeks and included both online and on-campus components. The study aimed to analyze the integration of MOOCs	The sample for the case study consisted of 23 students enrolled in a third-year course on Digital Signal Processing (DSP) as part of a five-year Electronics Engineering Program at Universidad Industrial de Santander.

ID	Population	Sample
	into traditional engineering education, particularly addressing the challenges and advantages of the MBF model in this context. Further details about the population are not provided in the context.	
P2.	The study population consisted of 222 engineering students from Taiwan and Vietnam.	The study sample consisted of 222 engineering students from two locations: 100 from Vietnam and 122 from Taiwan.
P3.	The study population consisted of 1,289 students primarily from Spanish-speaking countries, with a majority being male (64.4%) and an average age of 34 years (SD 9.5)	The sample consisted of 1,289 students primarily from Spanish-speaking countries who registered on a popular online educational platform.
P4.	The study population consisted of 122 students, including 113 full-time undergraduates and 9 part-time graduate students.	The sample consisted of 122 students, including 113 full-time undergraduates and 9 part-time graduate students, aged 19 to 35.
P5.	The research involved 295 participants, comprising 61 men and 39 women, who enrolled in two short xMOOC courses as verified users.	The research included a sample of 295 participants who enrolled in two short xMOOC courses as verified users, allowing them access to graded tasks.
P6.	The study population consisted of undergraduate students enrolled in the Computer Engineering course at the Federal University of Grande Dourados.	The sample for the experiment consisted of undergraduate students from the Computer Engineering course at the Federal University of Grande Dourados.
P7.	In some cases, population details were not explicitly reported in the original studies, indicating variability in reporting practices across the included literature.	The sample for the laboratory satisfaction survey consisted of approximately 30 students who completed experiments using the proposed virtual laboratory during the 2017 and 2018 semesters.
P8.	The research paper does not provide specific information regarding the population. However, it mentions a user study involving 14 M.Phil. and Ph.D. students aged 23 to 34 with diverse educational backgrounds, including social science, art and design, computer science, vehicle engineering, and architecture. Most of these participants have prior experience with traditional MOOCs. The study aimed to gather feedback on their experiences with different	The user study involved 14 M.Phil. and Ph.D. students, aged 23 to 34, with diverse educational backgrounds, including social science, art and design, computer science, vehicle engineering, and architecture.

ID	Population	Sample
	devices, including VR headsets, smartphones, and laptops, during a live demonstration of the MOMC platform. This diverse group reflects a range of academic disciplines and technological familiarity.	
P9.	The research population consisted of professionals currently practicing in various fields across the MENA (Middle East and North Africa) region.	The research sample consisted of 66 professionals from the MENA region, selected from an initial target of 78 participants.
P10.	The research paper does not provide specific information regarding population demographics or statistics. However, it mentions a pilot study involving 22 university students, aged between 22 to 40 years old, who were enrolled in the Computer Vision Master degree at Universidad Rey Juan Carlos (URJC)	The research paper presents Unibotics, an open online learning platform designed for practical robotics education. It allows users to edit and run robot programs directly from their browsers, providing over 20 academic units on various robotics topics. The platform utilizes the Gazebo simulator and ROS middleware, making it extensible for new exercises. It has been validated with 130 students across different university degrees, demonstrating its effectiveness in teaching robotics. Unibotics also features a web server built with Django, which manages user interactions and stores data in MySQL and Elasticsearch.

Challenges, Advantages, and Disadvantages of MOOC Implementation

The reviewed studies identify a consistent set of advantages and challenges associated with MOOC implementation in engineering education. Key advantages include accessibility, flexibility, and scalability, which align with the foundational promise of MOOCs as open educational platforms. However, persistent challenges such as high dropout rates, limited hands-on experience, language barriers, and resource constraints indicate structural limitations in current implementations. We argue that these challenges are not merely operational issues but reflect deeper misalignments between technological affordances and pedagogical requirements. For instance, high dropout rates can be interpreted as a consequence of insufficient instructional integration and lack of learner support mechanisms, rather than solely as learner-related factors. Similarly, limitations in practical skill development highlight the need for more effective integration of experiential learning tools such as virtual laboratories. These findings suggest that successful MOOC implementation requires a systemic approach that integrates instructional design, learner support, and technological infrastructure. Without such integration, MOOCs risk remaining supplementary tools rather than transformative educational systems.

Table 10. Challenges, Advantages, and Disadvantages of Massive Open Online Courses for Engineering Education in Journal Articles

ID.	Challenges	Advantages	Disadvantages
P1.	The first challenge identified is the need for higher resource investment in implementing the MBF model, requiring approximately 264 hours per course, which complicates course design.	The MBF model maximizes the synergy between online and on-campus components, enhancing student engagement and promoting complex problem-solving skills essential in Engineering education.	The implementation of the MBF model requires a significant investment of resources, with a reported dedication of approximately 264 hours per course, which can be a limitation in resource-constrained environments
P2.	The challenges faced by engineering students in MOOCs include low self-efficacy in English, particularly in reading materials, understanding video content, and delivering presentations. Students reported difficulties with vocabulary, pronunciation, grammar, and comprehension, which hindered their confidence in using English effectively.	The research highlights the importance of understanding MOOC self-efficacy, particularly among engineering students in different cultural contexts, which can inform better MOOC design and implementation.	The study acknowledges limitations regarding participants' self-reported data, as students may not accurately recall the number of MOOCs they attended or their English proficiency levels.
P3.	The paper discusses high dropout rates in Massive Open Online Courses (MOOCs), which often exceed 90%, as a significant challenge to retention and terminal efficiency, which is reported to be between 9.5 and 10%	The research highlights that implementing cognitive bias, specifically the 'Peanut effect,' can significantly reduce dropout rates in MOOCs, achieving a dropout rate as low as 74.2%.	The research highlights several disadvantages associated with MOOCs, particularly regarding retention rates, which can be as low as 9.5 to 10% for terminal efficiency, indicating a significant challenge in keeping students engaged.
P4.	The paper discusses several challenges related to MOOCs, including a high dropout rate compared to traditional online learning environments, which is a significant concern for educators and learners alike.	The study highlights that attending a blended MOOC significantly enhances students' self-efficacy, which is crucial for their academic success. This improvement in self-efficacy is linked to better academic performance, as students with higher self-efficacy levels	The study lacks a control group, which limits the ability to assess the true impact of the blended MOOC on self-efficacy and academic performance.

ID.	Challenges	Advantages	Disadvantages
		tend to achieve better scores.	
P5.	The paper discusses the challenge of teaching conceptual modeling, which is a non-tangible activity, through a learning-by-doing approach in a cloud-based environment. This method typically involves passive learning activities such as listening and answering multiple-choice questions, which do not allow students to practice building conceptual models or receive meaningful feedback on their performance.	MORTIF promotes active learning by allowing learners to engage in modeling tasks and receive immediate feedback, enhancing their understanding of the subject matter.	The contexts provided do not mention any specific disadvantages related to the MORTIF component or the study conducted. The focus is primarily on the benefits and effectiveness of MORTIF in enhancing learning through real-time feedback and active engagement. Therefore, there is no information available regarding any disadvantages associated with the implementation or use of MORTIF in the context of the research paper.
P6.	The paper identifies several challenges related to the application of SPOCs in software testing education during emergency remote teaching.	SPOCs provide a flexible learning environment, allowing students to access course materials at their own pace, which can enhance understanding and retention of information.	The study acknowledges limitations in controlling students' learning behavior, which may have been influenced by external factors or technical issues, such as internet access difficulties during the experiment.
P7.	The paper highlights the importance of understanding the specific challenges faced by students during experiments to improve satisfaction with the virtual laboratory system.	The virtual laboratory offers significant advantages in studying engineering improvements of various control algorithms, allowing for easier programming and experimentation compared to real laboratories.	The real laboratory's fixed mode and inflexible experiment time limit students' initiative and creativity, making it less adaptable to individual learning needs.
P8.	The paper discusses several challenges associated with traditional MOOCs, including the high autonomy of courseware creation leading to a loss of control for teachers and students, which compromises original teaching objectives.	MOMC inherits the diversity and flexibility of traditional MOOCs while integrating cutting-edge technologies like virtual reality and volumetric video, creating an embodied mixed-reality learning environment.	The current MOOC platforms lack a sense of immersion and emotional connection, leading to low student engagement and high dropout rates, with less than 10% of students completing courses.

ID.	Challenges	Advantages	Disadvantages
P9.	The challenges faced by learners in online courses are categorized into internal, external, and institutional challenges. Internal challenges relate to the characteristics of adult learners, such as time management and self-learning abilities, which are significant barriers	Online courses in technology and engineering provide a cost-effective and versatile way to learn new skills, making education accessible to a broader audience, including low-income students.	The lack of practical components in online courses is a significant disadvantage, as many participants noted that course delivery should focus more on practical applications rather than theoretical content. This absence makes it difficult for learners to follow along and apply their knowledge effectively
P10.	The paper discusses challenges related to the inconsistency of the Unibotics platform, particularly connection issues between the platform and components like Gazebo and the console, which affected user experience.	Unibotics is rated well for ease of use, allowing students to start working on exercises immediately after account creation.	Unibotics faced several disadvantages, primarily related to connectivity issues, which hindered students' ability to work comfortably on the platform. Many students reported that the platform was inconsistent due to these connection problems, especially when using the RADI in the computer farm

Integrative Synthesis of Instructional Models

Taken together, the results reveal that MOOCs in engineering education operate along a continuum of instructional integration. Standalone MOOCs prioritize accessibility and scale but face challenges related to engagement and skill development. Blended MOOCs provide structural alignment with curricular goals, virtual laboratories address practical competency requirements, and immersive MOOCs enhance experiential and affective dimensions of learning. This integrative synthesis demonstrates that no single instructional model sufficiently addresses all pedagogical demands of engineering education. Instead, effective MOOC implementation emerges from strategic combinations of blended structures, virtual experimentation, and immersive engagement tailored to specific learning objectives and contexts.

Conceptual Framework: Integrated MOOC Pedagogical System for Engineering Education

Figure 2 shows the conceptual framework of MOOCs in engineering education as an integrated pedagogical system. The framework illustrates how instructional integration through blended, virtual, and immersive models activates pedagogical mechanisms that shape learning outcomes, while implementation sustainability is influenced by contextual conditions and supported by constructivist, experiential, and technology-enhanced learning perspectives.

The conceptual framework positions MOOCs in engineering education not as standalone digital platforms, but as an integrated pedagogical system. At the structural level, MOOCs are embedded through instructional integration, particularly via blended learning, virtual laboratories, and immersive environments. These instructional forms activate key pedagogical mechanisms, namely cognitive engagement, experiential learning, and interaction with feedback, which in turn lead to meaningful learning and development outcomes such as higher-order thinking, practical engineering competencies, self-efficacy, engagement, and persistence. At the final level, the sustainability of MOOC implementation depends on contextual conditions, including accessibility, scalability, learner diversity, and institutional as well as technological readiness. The framework is theoretically underpinned by constructivist learning, experiential learning, and technology-enhanced learning perspectives, while the four research questions collectively inform its methodological, pedagogical, learner-centered, and implementation dimensions.

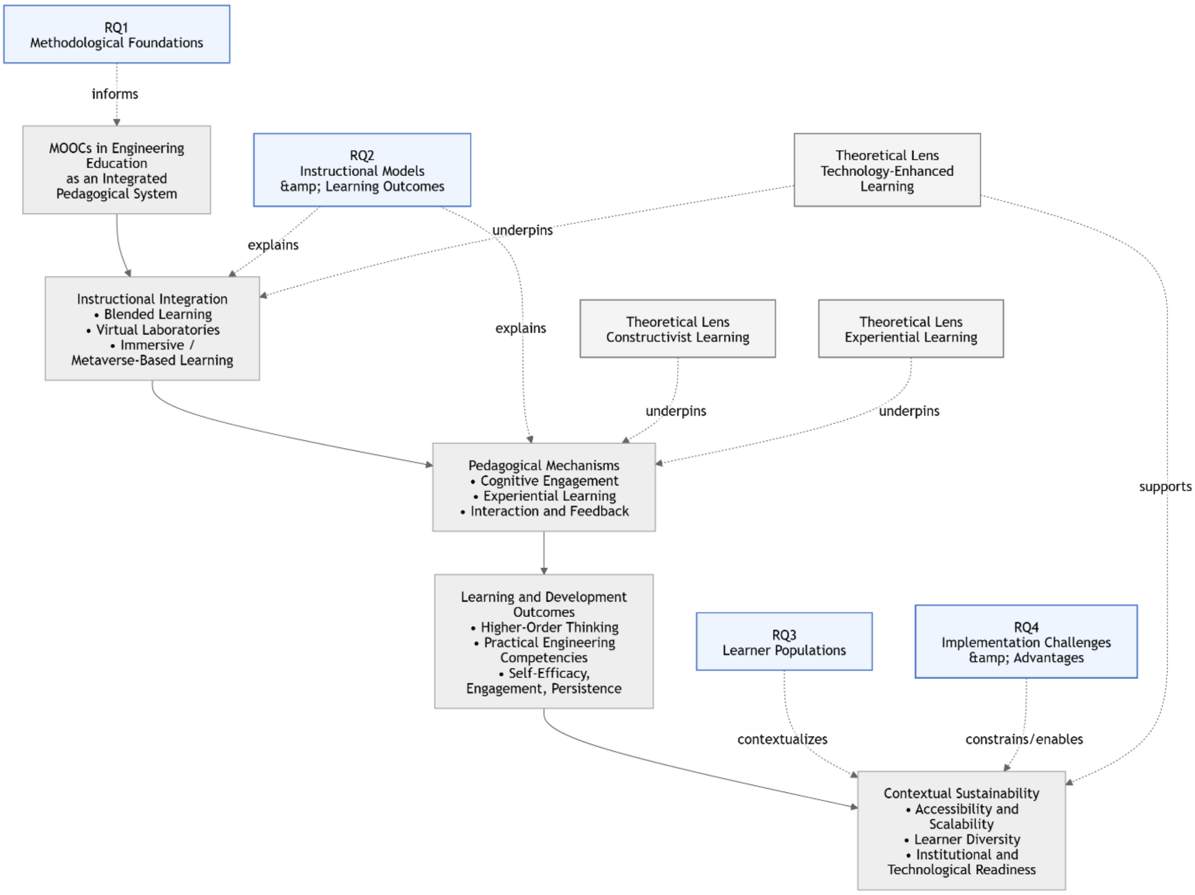

Figure 2. Conceptual Framework Diagram: Integrated MOOC Pedagogical System for Engineering Education

These findings collectively indicate that methodological design (RQ1), instructional models (RQ2), learner characteristics (RQ3), and implementation conditions (RQ4) are interdependent rather than independent dimensions, reinforcing the need for an integrated conceptual approach. These findings collectively demonstrate that methodological design, instructional models, learner characteristics, and implementation conditions are interdependent dimensions, reinforcing the need for an integrated conceptual approach to MOOCs in engineering education.

Discussion

The findings of this systematic review, interpreted through the proposed conceptual framework, suggest that MOOCs in engineering education should not be conceptualized as standalone instructional platforms. Rather, we argue that their effectiveness is contingent upon their integration within structured pedagogical systems that align instructional design, learner engagement, and technological affordances. This perspective advances prior literature by reframing MOOCs from delivery mechanisms to components of an integrated learning architecture.

Consistent with this interpretation, blended learning emerges as a foundational structural mechanism that enables such integration. Previous studies have demonstrated that MOOC-based flipped classrooms facilitate higher-order cognitive engagement through problem-based and application-oriented activities (Pertuz et al., 2023; Freeman et al., 2014). However, this pattern should not be interpreted as evidence that blending modalities alone ensures effectiveness. Instead, we contend that blended learning functions by redistributing instructional roles, allowing asynchronous environments to support foundational knowledge acquisition while synchronous or guided activities promote deeper conceptual processing. This structural alignment directly addresses well-documented limitations of MOOCs, including learner isolation and surface-level engagement, by embedding them within coherent curricular systems.

At the experiential level, virtual laboratories represent a critical mechanism for translating theoretical knowledge into practice. The reviewed evidence indicates that simulation-based environments support iterative experimentation, immediate feedback, and procedural skill development, which are essential components of engineering education (De Jong et al., 2013; Potkonjak et al., 2016). From a theoretical standpoint, this finding reinforces the relevance of experiential learning principles in digital contexts. Nevertheless, these results should not be interpreted as suggesting that virtual laboratories can fully replace physical laboratories. Rather, their pedagogical value lies in extending opportunities for practice and conceptual reinforcement, particularly in contexts where access to physical resources is limited. This highlights the importance of instructional design in mediating the relationship between technological tools and learning outcomes.

Furthermore, immersive and metaverse-based MOOCs extend the framework by introducing affective and embodied dimensions of learning. Technologies such as virtual reality and volumetric video have been shown to enhance presence, motivation, and learner engagement, which are closely linked to persistence and self-efficacy in online environments (Zhang et al., 2023; Phan, 2023). We argue that these environments function as engagement amplifiers, particularly in engineering domains where spatial reasoning and system visualization are essential. However, their effectiveness is highly context-dependent. Factors such as technological infrastructure, accessibility, and alignment with pedagogical objectives significantly influence their scalability. Therefore, immersive technologies should not be viewed as universally superior solutions, but as context-sensitive tools whose impact depends on their integration within broader instructional systems.

Importantly, the findings also reveal that the benefits and challenges of MOOCs are structurally interconnected rather than independent. While MOOCs offer clear advantages in terms of accessibility, flexibility, and scalability, persistent issues such as high dropout rates, limited hands-on experience, and language barriers reflect deeper misalignments between technological affordances and pedagogical requirements. We contend that these challenges should not be interpreted solely as learner-related deficiencies, but as indicators of insufficient instructional integration and support mechanisms. This interpretation shifts the focus from learner behavior to system design, emphasizing the need for holistic approaches that integrate pedagogy, technology, and learner support.

Taken together, this study advances the theoretical understanding of MOOCs in engineering education by demonstrating that their effectiveness depends on the interaction between structural, experiential, and contextual dimensions. The proposed framework provides a basis for interpreting these interactions and highlights the importance of moving beyond fragmented implementations toward integrated pedagogical systems. This perspective not only clarifies inconsistencies in prior findings but also offers a foundation for future research aimed at developing scalable and contextually adaptive MOOC-based learning environments.

Conclusion

This systematic literature review provides a theoretically informed synthesis of recent empirical research on MOOCs in engineering education, demonstrating that their effectiveness depends fundamentally on pedagogical integration rather than isolated implementation. Drawing on evidence from studies published between 2020 and 2024, we argue that MOOCs should not be understood as independent instructional technologies, but as components of integrated learning systems that align instructional design, learner engagement, and contextual conditions.

The findings reveal that three interrelated instructional dimensions blended learning, virtual laboratories, and immersive or metaverse-based environments function as complementary mechanisms within this integrated system. Blended learning enables structural alignment between MOOCs and formal curricula, supporting higher-order cognitive engagement (Pertuz et al., 2023; Freeman et al., 2014). Virtual laboratories extend experiential learning by facilitating procedural skill development and iterative practice in digital environments (De Jong et al., 2013; Potkonjak et al., 2016). Immersive technologies further enhance affective and embodied dimensions of learning, contributing to motivation, engagement, and persistence (Zhang et al., 2023; Phan, 2023). Collectively, these findings confirm that effective MOOC implementation in engineering education requires the coordinated interaction of structural, experiential, and affective elements.

Importantly, this study advances the field by proposing a conceptual framework that integrates these dimensions into a coherent pedagogical model. Unlike previous research, which has largely adopted descriptive or fragmented approaches, this framework provides a theoretically grounded explanation of how instructional design, learner interaction, and technological affordances interact to produce meaningful learning outcomes. In this sense, the contribution of this study extends beyond synthesis toward theory development, offering a foundation for interpreting and designing MOOC-based learning environments in engineering education. Unlike prior studies that examine MOOCs in isolation, this framework integrates structural, experiential, and contextual dimensions simultaneously, providing a comprehensive explanatory model for engineering education.

At the same time, the findings highlight persistent challenges that constrain the effectiveness of MOOCs, including high dropout rates, limited hands-on experiences, language barriers, and variability in technological infrastructure. We contend that these challenges should not be viewed solely as limitations of MOOCs themselves, but as indicators of insufficient integration between pedagogical design and contextual conditions. This perspective shifts the focus from technological capability to systemic alignment, emphasizing the need for holistic approaches that integrate instructional strategies, learner support, and institutional readiness (Margaryan et al., 2015; Onah et al., 2014).

Despite its contributions, this study is subject to certain limitations. The review included a relatively small number of studies (n = 10), reflecting the application of strict inclusion and quality criteria. While this approach enhances the reliability and relevance of the findings, it may limit the breadth of perspectives captured. Additionally, the reliance on studies indexed in ERIC and Scopus may exclude relevant research published in other sources. These limitations should be considered when interpreting the generalizability of the findings.

Future research should extend this work in several directions. First, there is a need for theory-driven empirical studies that move beyond outcome validation toward explanatory modeling of MOOC effectiveness. Second, longitudinal and large-scale studies are required to examine the sustainability and long-term impact of integrated MOOC-based learning systems. Third, further research should explore the interaction between learner characteristics, instructional design, and contextual variables to develop adaptive and personalized MOOC environments. Finally, emerging technologies such as artificial intelligence and advanced immersive systems offer new opportunities for enhancing engineering education, but their integration requires careful alignment with pedagogical principles and institutional capacities.

In conclusion, this study provides a comprehensive and theoretically grounded understanding of MOOCs in engineering education, emphasizing that their transformative potential lies not in their technological features alone, but in their integration within coherent pedagogical systems. This perspective offers important implications for researchers, educators, and policymakers seeking to design scalable, effective, and contextually responsive learning environments in the evolving landscape of engineering education.

Recommendations for Practice and Future Research

Recommendations for Practice

Based on the synthesized evidence and the proposed conceptual framework, practitioners and institutions should prioritize the pedagogical integration of MOOCs rather than their standalone deployment. MOOCs should be strategically embedded within blended learning structures to align online content with curricular objectives and support higher-order cognitive engagement. For engineering education in particular, the incorporation of virtual laboratories is strongly recommended to address the need for experiential and procedural skill development, especially in contexts where access to physical laboratories is limited. Furthermore, immersive and metaverse-based technologies should be adopted selectively to enhance learner engagement, presence, and motivation, provided that sufficient technological infrastructure and instructional design expertise are available. Institutions should also invest in faculty development and instructional design support to mitigate resource demands and ensure sustainable implementation.

Recommendations for Future Research

Future research should empirically test the proposed conceptual framework through theory-driven and hypothesis-based designs, such as experimental, quasi-experimental, or structural equation modeling approaches. Longitudinal studies are needed to examine the sustained effects of integrated MOOC models on learning outcomes, retention, and professional skill development. Additionally, comparative studies across cultural and institutional contexts would enhance understanding of moderating factors such as language proficiency, learner readiness, and technological access. Further research should also explore cost-effectiveness and scalability issues associated with immersive and virtual laboratory–enhanced MOOCs to inform evidence-based decision-making in engineering education.

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