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Transforming engineering education in the digital era: findings from a systematic review

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Introduction: According to the Digital Curricula Report on the status of online learning in higher education in the United States, about one-third of higher education is online, a number that has substantially increased after the pandemic (Analytics, 2022). As of October 1, 2024, the Accreditation Board for Engineering and Technology (ABET) has accredited 3,611 programs across 702 institutions in the United States, but only 46 institutions offered 100% online programs, which is significantly lower than other fields. This study aims to explore the factors that influence the acceptance of online learning and teaching in engineering education from the perspectives of students and teachers after the COVID-19 pandemic.

Methods: This study followed the PRISMA guidelines and included only peer-reviewed articles published between 2020 and 2024, focusing on online engineering education. This systematic review explored the variables affecting student and teacher acceptance of online learning in order to more clearly define challenges in delivering online engineering education and to identify avenues to improve and strengthen it. The inclusion criteria focused on articles addressing instructional design and learning experiences in online education, while the exclusion criteria eliminated studies without key data and those outside the specified timeframe.

Discussion: The findings of this systematic review highlighted several factors influencing the acceptance of online engineering education, such as technology design, individual characteristics, and social factors. These factors are important for creating effective, engaging, and accessible learning environments that enhance student performance and satisfaction. Further research is needed to develop an approach to examine factor interactions in different contexts, and create a framework aligned with ABET accreditation standards for assessing long-term learning outcomes.

KEYWORDS

online education, engineering education, student acceptance, online technology transform, modern engineering education

Introduction

Traditionally, a school of engineering is divided into four areas, Mechanical, Chemical, Civil, and Electrical, with various sub-majors in each discipline. In recent years, the number of engineering degrees has expanded significantly, and additional subcategories have emerged under each discipline. In today's fast-paced changes of the modern world, engineering education is increasingly emphasizing interdisciplinary connections that reflects the growing complexity of real-world challenges (Broo et al., 2022). Despite this growth, the National Academy of Sciences and the National Academy of Engineering reported that there is still a shortage of engineering professionals in the United States. Engineering degrees are generally respected when earned from an accredited program, such as those recognized by the Accreditation Board for Engineering and Technology (ABET). All ABET-accredited programs, whether delivered online or in-person, are evaluated based on the same criteria. In fact, employers prioritize skills over the format in which an engineering degree was earned, still having greater value on demonstrated competencies than on whether the education was completed online or in person (Broo et al., 2022).

While there is an increasing trend among universities to offer online courses, this transition is particularly challenging in engineering, where traditional programs rely heavily on the practical application of scientific and technological principles. The unforeseen impact of COVID-19 forced engineering universities to shift their courses online, even for students who might not have chosen this mode of learning (Baltà-Salvador et al., 2021). Some engineering disciplines are harder to offer online because of their hands-on nature. For example, students pursuing degrees in fields like mechanical engineering may need to attend campus for practical lessons. In contrast, technology-focused engineering specialties may be more suitable for fully online education (Follman, 2024). This is one of the reasons why fewer than fifty ABET-accredited engineering programs are fully available online.

According to Hadgraft and Kolmos (2020), engineering education must evolve to provide new types of learning that equip future engineers with the skills and competencies needed across various disciplines. One promising path for this transformation is digital and online learning, which allows for the personalization of curricula tailored to students' individual learning styles and career paths. Online education delivers course content entirely through digital platforms and offers students flexibility by allowing them to access learning materials at their own pace (Stern, 2020). This student-centered approach empowers learners to take charge of their education, while instructors guide the process (Al-Salman and Haider, 2021). Learning Management Systems (LMS) also play a key role in facilitating online learning by providing features that enhance interactivity and improve student learning experiences. LMS platforms are designed to organize course materials, communicate with students, and structure online class activities (Almahasees et al., 2021; Demmans Epp et al., 2020).

Following the COVID-19 pandemic, many educational institutions shifted entirely to online formats to ensure continuity of learning (Sepasgozar, 2020). Elumalai et al. (2021) analyzed seven important factors that control the quality of e-learning in higher educational institutions: administrative support, course content, course design, social support, technical support, instructor characteristics, and learner characteristics. There is a need for improvement in administrative support and course content design to enhance the quality of e-learning. As higher education increasingly adopts online learning, it is essential to conduct a more comprehensive analysis of its role in engineering education, examining factors such as teaching effectiveness, acceptance rates, and the unique challenges of online learning.

This systematic review aims to explore the factors that collectively influence online engineering education and the variables identified in recent studies to assess the potential for expanding fully online engineering programs. The insights gained from this review will be valuable in promoting more fully online engineering programs. The research questions (RQs) are as follows:

> *RQ1*: What are the descriptive characteristics (e.g., type of participants, sample size, research topic, and methodology) of the reviewed studies?
>
> *RQ2*: What variables have been identified as influencing the acceptance of online learning and teaching in engineering education?
>
> *RQ3*: How do the identified factors affect the acceptance of online learning and teaching in engineering education, and what do these factors reflect about the importance of the acceptance?

Background

Engineering education transformation

Engineering education has undergone significant transformation over the past several decades, driven by advances in technology, globalization, and evolving workforce demands. Historically, engineering education followed a rigid, discipline-specific model, focusing primarily on mathematics, physics, and engineering principles, with an emphasis on theoretical knowledge (Chen et al., 2022). The curriculum was structured around lectures, exams, and laboratory experiments designed to develop analytical and technical skills that met industry needs at the time (Broo et al., 2022; Miranda et al., 2021). However, the traditional model of engineering education, which focuses heavily on technical expertise and problem-solving, has been critiqued for its limited focus on the broader competencies needed by today's engineers. These include communication skills, teamwork, leadership, and the ability to work across disciplines (Hadgraft and Kolmos, 2020). As the nature of engineering challenges has evolved, there has been increasing emphasis on producing well-rounded engineers capable of tackling complex, multidisciplinary problems. The rapid pace of technological change and the increasing complexity of global engineering challenges require engineers to be adaptable, innovative, and capable of working in diverse, interdisciplinary teams.

In addition to these evolving educational needs, there are other challenges regarding the diversity of student populations. Science & Engineering Indicators data showed that, in 2021, a larger portion of foreign-born workers held STEM occupations (26%) than U.S.-born workers (24%). Proportionally, more naturalized citizens worked in S&E-related occupations (11%) than noncitizens (5%) or U.S.-born citizens (9%). Additionally, larger proportions of noncitizens worked in STEM middle-skill occupations (12%) than naturalized citizens (8%) or U.S.-born workers (9%).

Moreover, women, African Americans, and Hispanics remain underrepresented in both undergraduate and faculty positions, with the percentage of engineering bachelor's degrees awarded to women and minority groups decreasing in recent years. These trends highlight the ongoing challenges in attracting and retaining a diverse range of students and faculty in engineering, posing a significant threat to the U.S.'s position as a global leader in science and technology. To maintain its competitive edge, the U.S. must address these issues and reverse the declining diversity and retention rates in engineering education.

The transformation of engineering education began to take shape in 2009, marking the transition to what we now consider modern engineering education. The modern approach reflects the growing recognition that engineering professionals must possess not only strong technical skills but also the ability to think creatively and collaborate across disciplines. As a result, there has been a shift toward more holistic, student-centered learning models that emphasize interdisciplinary approaches, project-based learning (PBL), and active learning techniques (Johri and Olds, 2011). Looking ahead, the future of engineering education will likely involve an increased focus on interdisciplinary learning, global collaboration, and the integration of emerging technologies such as artificial intelligence (AI), robotics, and data science. As the boundaries between engineering disciplines continue to blur, educational institutions will need to adapt their curricula to provide students with a broad, flexible skill set that prepares them for a rapidly changing technological landscape (Miranda et al., 2021). Online platforms, micro-credentials, and certification programs will play an important role in providing ongoing learning opportunities as engineers seek to update their skills in response to new challenges and innovations (Asgari et al., 2021).

Online learning effectiveness in engineering education

Since the COVID-19 pandemic, online education is no longer a new concept to educators. According to UNESCO, more than 1.5 billion students worldwide have taken online courses, and most institutions around the world have now adopted a variety of class formats. However, according to Asgari et al. (2021), engineering education, particularly for vulnerable, disadvantaged, and underrepresented students, presents significant challenges that go beyond academic responsibilities. These students often face additional burdens, such as family obligations, financial stress, and the need for supplementary employment when they study online. To ensure that these students receive a high-quality education, it is essential to take extra measures to ensure that online engineering courses continue to meet the rigorous standards set by program accrediting bodies, such as the Accreditation Board for Engineering and Technology (ABET).

Baltà-Salvador et al. (2021) found that online classes were beneficial for engineering students when they were designed in specific ways that could be useful for future university or online courses. One of the main advantages of online learning is its ability to offer greater accessibility, particularly for students who may be geographically distant, working professionals, or those with other constraints that prevent them from attending traditional, in-person classes (Li et al., 2021). Online learning environments allow students to access course materials at their own pace, which can improve learning outcomes, especially for those who benefit from repetition or self-directed study (Bawa, 2016). Students especially valued the quick, accessible communication possible in online formats, as well as personalized support such as individual or small group video calls (Baltà-Salvador et al., 2021).

Another benefit of online learning is course adaptations. Features such as online lecturers' recordings for later review, sharing solved problems for self-correction, and providing supplementary videos were seen as crucial for enhancing student learning. Teachers' responsiveness, supportive attitudes, and willingness to seek feedback from students were also key factors in improving the learning experience (Baltà-Salvador et al., 2021). Feedback benefits both teachers and students, making students feel heard and valued (Navarro et al., 2021; Sorce and Issa, 2021). Rey and Defensor (2024) found that many online courses incorporate innovative tools such as simulations, virtual labs, and interactive 3D models, which can be particularly beneficial in engineering fields where complex concepts and designs need to be visualized and experimented with. These tools can replicate the hands-on learning experiences traditionally offered in physical labs.

The effectiveness of online learning in engineering education depends on various factors, including course design, student engagement, instructor support, and the use of innovative technologies (Devkota et al., 2021). While challenges such as the lack of hands-on experience and technological barriers remain, there is significant potential for online learning to provide accessible, cost-effective, and flexible learning opportunities for engineering students (Langar et al., 2021). Successfully implementing online learning in engineering requires a thoughtful approach that incorporates blended learning models, active learning strategies, and the integration of virtual labs and simulations to maintain the rigor and practical experience necessary in engineering education. As online learning continues to evolve, ongoing research and adaptation will be key to addressing the challenges and maximizing its effectiveness in engineering education.

Method

This study follows the PRISMA guidelines (Brennan and Munn, 2021). To ensure the integrity of the research, peer-reviewed articles and conference papers were considered for inclusion. The necessity for online education intensified as a result of the pandemic. The data parameters for this review covered studies conducted between 2020 and 2024, capturing the most recent research on online education in engineering. The article selection process is outlined in Figure 1.

Search strategy

The literature search utilized multiple scholarly repositories and databases to ensure a diverse and comprehensive dataset. The primary sources included *ERIC, Google Scholar, ACM, Scopus,* and *PsycInfo*, which were chosen for their broad access to peer-reviewed literature across disciplines. The databases offer targeted coverage of educational practices, student behavior, and the application of technology in teaching, making them more appropriate for addressing the research questions regarding online learning acceptance, student engagement,

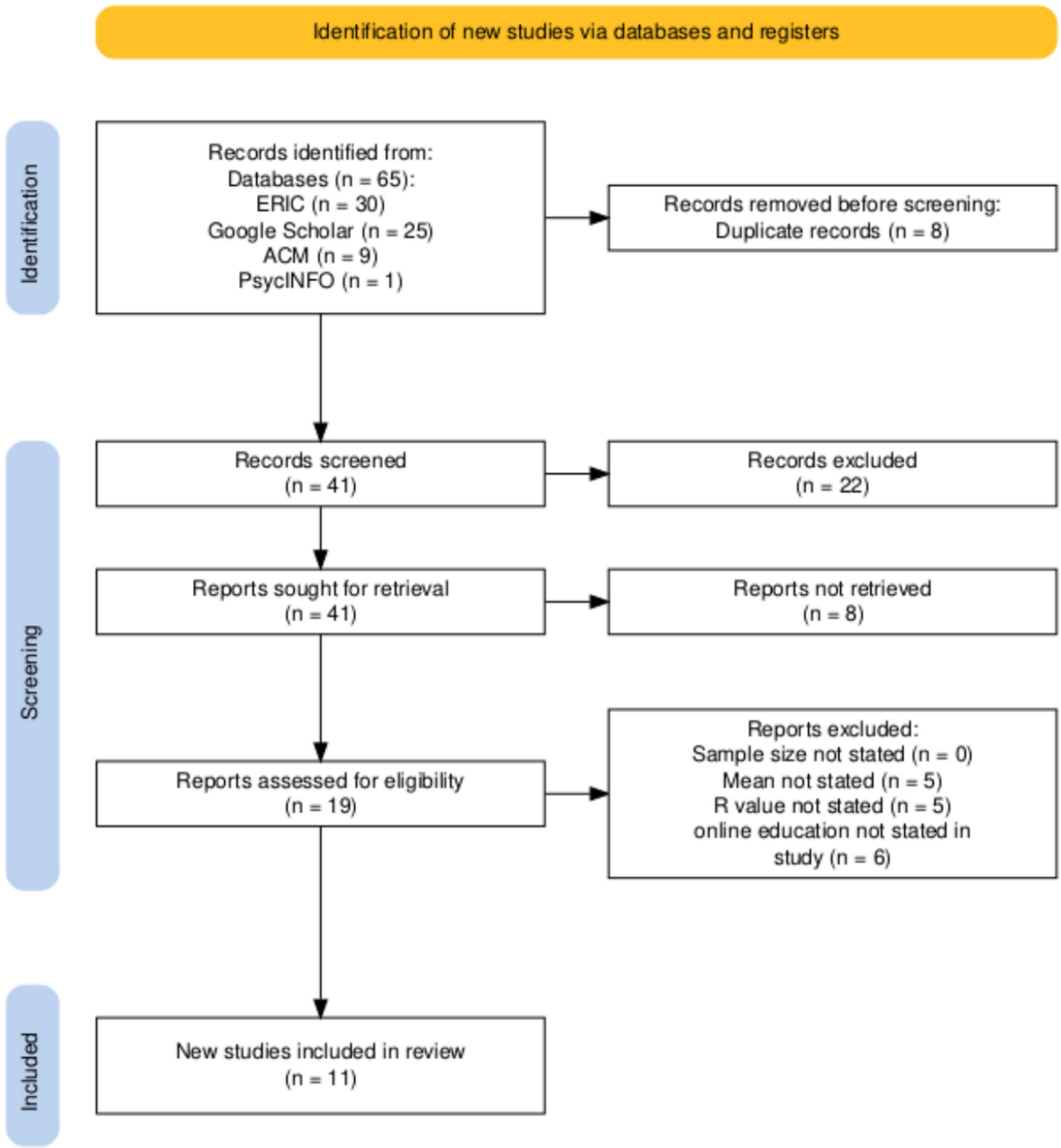

FIGURE 1
PRISMA article selection process.

and the effectiveness of online engineering programs. In particular, *Scopus* and *Google Scholar* have captured a broad range of educational content across disciplines. This ensures that the review includes studies addressing both the pedagogical and technological aspects of online education.

Based on the purpose of this study, although *IEEE Xplore* is an important resource for engineering research, the chosen databases are more inclusive of the educational methodologies and interdisciplinary approaches necessary for a holistic review of online engineering education. Including *IEEE Xplore* could limit the scope to highly technical articles that do not address the pedagogical challenges and outcomes of online engineering education. The databases *IEEE Xplore* and *Web of Science* were excluded from the search due to their primary focus on highly technical, engineering-specific content. While these databases provide important engineering research, they are less focused on educational theory, learning outcomes, and pedagogical methodologies, which are central to our review of online engineering education.

The systematic review process began with a detailed breakdown of the research topic and its core components, allowing for the creation of a structured and targeted search strategy. Keywords and phrases were identified to reflect the central themes of the topic.

These keywords were chosen for their ability to encompass the scope of the inquiry and included terms such as *online engineering education*, *acceptance*, *satisfaction*, *technology acceptance model (TAM)*, *performance*, *factor analysis*, and *regression*. The Boolean search method was employed to combine these keywords strategically, using operators such as "AND" and "OR" to refine searches and create tailored keyword variations. This approach ensured comprehensive coverage of the literature while minimizing the inclusion of irrelevant studies. The search strategy also incorporated iterative refinement, with adjustments made based on the relevance and quality of initial search results. The following search strings were used for searching.

Search string: ((engineering education) AND (online learning)).

Online acceptance substring: "online acceptance" OR "satisfaction" OR "technology acceptance model (TAM)" OR "performance" OR "outcome."

Methodology substring: "quantitative research" OR "experimental research" OR "factor analysis" OR "regression."

Inclusion and exclusion criteria

The search was restricted to articles published between 2020 and 2024 to focus on recent and impactful research. This timeframe was selected to capture key developments in online learning during the COVID-19 pandemic and the following years. Transition to online education and its evolving nature became a critical area of study during this period. By focusing on this timeframe, the review aimed to contextualize these changes while connecting them to broader trends and potential future directions in the field.

The studies needed to meet the following conditions to be included in the review: Inclusion criteria were based on study design, participants, intervention, outcomes, time frame, language, and setting. Excluded studies are those that lacked peer review, focused on unrelated topics, or fell outside the specified publication period. Additionally, to refine our article search, we excluded articles that do not report key data, such as sample size, mean, standard deviation, analysis numbers, empirical studies, acceptance and satisfaction variables, and regression coefficients. The inclusion and exclusion criteria are described in Table 1.

TABLE 1 Inclusion and exclusion criteria.

Inclusion	Exclusion
• Studies published in peer-reviewed journals and conference proceedings. • Empirical studies involving participants enrolled in higher education engineering programs. • Studies focused on online interventions in engineering education. • Research that reports on outcomes related to student performance, satisfaction, motivation, or learning experience. • Studies published between 2020 and 2024. • Studies published in English. • Studies that include students, instructors, or both as participants.	• Studies that focus on face-to-face or purely traditional learning settings without online components. • Studies not involving higher education students (e.g., K-12, corporate training). • Non-empirical studies, such as opinion pieces, editorials, and theoretical reviews. • Studies that do not report on any of the predefined outcome measures related to online learning in engineering. • Studies published before 2010 or after 2024. • Studies not published in English. • Studies that focus on unrelated to engineering education.

Relevance and screening

The initial search yielded 65 scholarly articles. These articles were subjected to a two-stage screening process. In the first stage, titles and abstracts were reviewed to identify articles that aligned with the inclusion criteria, reducing the pool to 41 articles.

In the second stage, the full texts of the remaining articles were examined to assess their relevance and quality more thoroughly. Particular attention was paid to whether the studies explicitly addressed the integration of instructional design models and learning theories, especially in online learning during or after the COVID-19 pandemic. This detailed screening process narrowed the final selection to 11 articles most pertinent to the research objectives. Examples of the articles that were omitted can be found in Table 2.

This rigorous, systematic approach to the literature review ensures a comprehensive synthesis of contemporary research, establishing a clear link between past trends, current developments, and future directions in the study of instructional design and learning experiences in online engineering education. By methodically narrowing the initial pool of 65 articles to a final set of 11, the review provides a focused and in-depth analysis that contributes to a deeper understanding of the research topic.

Results

Based on our search, we identified a significant gap in the literature on online engineering education. The final set of articles consisted of eleven peer-reviewed conference and journal articles published between 2020 and 2024, which analyzed the effectiveness of online engineering education and its potential for expanding fully online engineering programs. The eleven reviewed articles provided valuable information for answering our research questions.

> *RQ1*: What are the descriptive characteristics (e.g., type of participants, sample size, research topic, and methodology) of the reviewed studies?

The descriptive characteristics of the included studies vary, based on the information provided in the articles. Participants in most of the studies are across a range of engineering programs. The sample size in all included studies exceeds one hundred students. The research topics span a variety of themes related to online learning, technology adoption, and student experiences. The included articles primarily focus on engineering students' experiences with online learning, utilizing diverse methodologies and theoretical frameworks to explore motivation, satisfaction, usability, and self-directed learning readiness. Table 3 outlines the specific research topics covered in the included

TABLE 2 Examples of articles omitted from the review.

Study title	Author(s) and year	Reason for exclusion
Research on the interdisciplinary competence and its influencing factors of engineering college students under the emerging engineering education	Zhang (2021)	Online education is not stated in the study
A quantitative analysis of self-efficacy, causal attributions, academic performance, personal characteristics, and life at university: an engineering education outlook	Schirichian et al. (2022)	
Course satisfaction in engineering education through the lens of student agency analytics	Heilala et al. (2020)	
Effects of a first-year undergraduate engineering design course: survey study of implications for student self-efficacy and professional skills, with focus on gender/sex and race/ethnicity	Sperling et al. (2024)	
Factors of the technology acceptance model for construction it	Park and Park (2020)	
Measuring the programming self-efficacy of electrical and electronics engineering students	Kittur (2020)	
Research on influencing factors of engineering students' classroom satisfaction based on factor analysis theory from the perspective of general education	Yan et al. (2021)	
The impact of achievement goal orientation, learning strategies, and digital skill on engineering skill self-efficacy in thailand	Chonsalasin and Khampirat (2022)	

TABLE 3 Research topics for included articles.

Research topics	Included articles
Motivation for online STEM learning	Helmi et al. (2024), Sung and Huang (2024), Li and Liu (2024), Wang et al. (2023), Zogheib (2024), and Luo and Yuan (2024)
Satisfaction with Learning Management Systems (LMS)	Rey and Defensor (2024), Navarro et al. (2021), and Luo and Yuan (2024)
Usability of e-learning modules and platforms	Rey and Defensor (2024), Wang et al. (2023), and Luo and Yuan (2024)
Self-directed learning readiness	Watson et al., 2024
Impact of online learning on students	Quinto et al. (2024), Sorce and Issa, 2021, and Zogheib (2024)

studies. Nine of the studies employ quantitative research, and two of the studies use mixed methods approaches.

> *RQ2*: What variables have been identified as influencing the acceptance of online learning and teaching in engineering education?

Based on the included articles, we identified four categories of variables (technology-related, individual-related, social and environmental, and outcome-related) that influence the acceptance of online learning and teaching in engineering education (see Figure 2). A comparison of the findings from different studies reveals significant patterns, but also areas of divergence.

Technology-related variables

These variables relate to the technology topics and learning management systems in online engineering education.

Variable 1–perceived usefulness

The usefulness of the technology is one variable that impacts the positive acceptance of online engineering education. Navarro et al. (2021) and Zogheib (2024) identified that using a particular technology, such as Google Classroom or a Learning Management System (LMS), can enhance students' academic performance. Studies also show that perceived usefulness positively influences attitudes toward technology and the intention to use it.

Variable 2–perceived ease of use

The degree to which students believe that using technology is free of effort impacts the acceptance of online learning (Navarro et al., 2021; Zogheib, 2024; Rey and Defensor, 2024). Ease of use is a significant factor in technology adoption; the ease with which students can use a given technology influences students' behavioral intentions and engagement (Navarro et al., 2021; Zogheib, 2024).

Variable 3–technology characteristics

The features and capabilities of the technology provided influence its acceptance and how well it fits online teaching and learning. The quality and relevance of the materials available on the

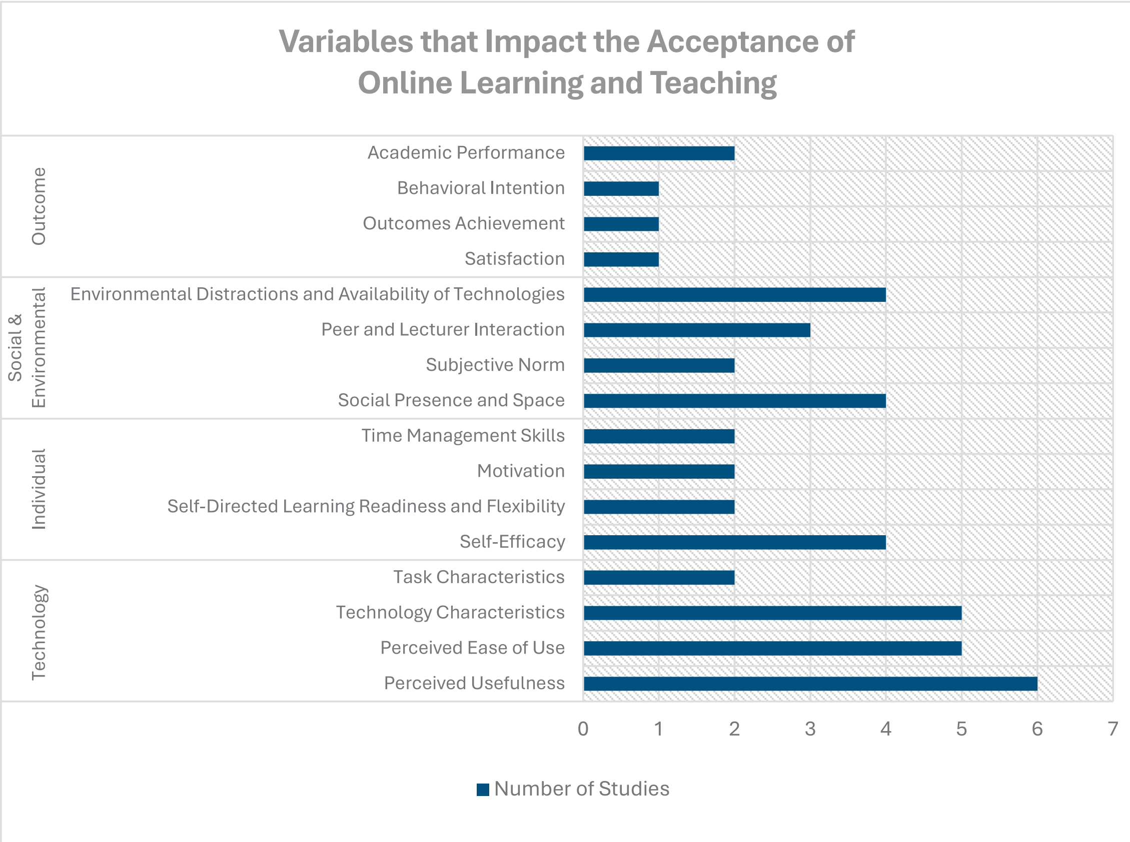

FIGURE 2
Characteristics and variables that impact online learning and teaching in engineering education.

platform affect student satisfaction. Additionally, system accessibility refers to students' ability to easily access the online platform, which is relevant to technology acceptance (Navarro et al., 2021; Zogheib, 2024).

Variable 4—task characteristics

The nature of online learning tasks significantly impacts technology adoption. Different types of online learning tasks influence students' acceptance of technology in education (Navarro et al., 2021).

In summary, this review supports the idea that perceived usefulness and ease of use are key factors in the Technology Acceptance Model (TAM) for online learning acceptance. According to TAM, these perceptions can also predict behavior (Han and Sa, 2022).

A new finding regarding technology-related variables is the role of technology characteristics and task characteristics. However, Han and Sa (2022) also noted that students' perceptions of usefulness are highly context dependent. While some students in certain engineering disciplines found specific tools like Google Classroom beneficial for their learning, others struggled with platform limitations, showing a contradiction in findings regarding platform preference. The degree to which ease of use impacts acceptance varied across studies. Navarro et al. (2021) reported a strong correlation between ease of use and student engagement, while other studies suggested that perceived ease of use may be secondary to factors like course content and peer interactions in shaping overall acceptance (Luo and Yuan, 2024). These contradictions highlight the need for a deeper examination of how ease of use interacts with other variables.

Individual-related variables

These variables relate to the personal attributes of learners that influence technology adoption in online engineering education.

Variable 1—self-efficacy

This refers to an individual's belief in their ability to succeed in using technology. Self-efficacy significantly affects a student's willingness to engage with online learning (Zogheib, 2024).

Variable 2—self-directed learning readiness and flexibility

Assessing students' preparedness to learn independently is important for their success in online education. Studies suggest that self-directed learning skills are important for engineering students (Watson et al., 2024). Additionally, Watson et al. (2024) also highlight students' flexibility as an important skill for adapting to an online learning environment.

Variable 3—motivation

Motivation is the driving factor behind students' engagement in learning activities. It was found to be significantly important for students who accept learning online (Helmi et al., 2024; Rey and Defensor, 2024; Sung and Huang, 2024).

Variable 4—time management skills

The ability of students to manage their time has been identified as a key component to success in online learning (Quinto et al., 2024; Watson et al., 2024).

In summary, individual characteristics such as self-efficacy, motivation, and self-directed learning readiness were found to play important roles in shaping students' acceptance of online learning. However, how self-efficacy is measured and interpreted is not consistent. Watson et al. (2024) reported that students with high self-efficacy showed greater adaptability to online learning, whereas Quinto et al. (2024) found that students with lower self-efficacy might still succeed in online education when other supportive factors, such as peer interactions and instructor guidance, were present. Motivation, both intrinsic and extrinsic, was highlighted as a key factor for acceptance (Sung and Huang, 2024). However, intrinsic motivation may be less significant in online environments for students who lack strong self-regulation skills, pointing to the importance of time management and self-directed learning readiness (Watson et al., 2024).

Social and environmental variables

These variables relate to factors, conditions, or surroundings in online learning that can influence outcomes.

Variable 1—social presence and space

Social presence is the sense of being connected with others in the online environment and has been shown to impact perceived satisfaction for online learning (Navarro et al., 2021). Social space encompasses the opportunities for interaction and collaboration within the online platform. Like social presence, it also influences students' perceived satisfaction with online learning.

Variable 2—subjective norm

This refers to the influence of social circles and expectations on a student's technology adoption (Zogheib, 2024).

Variable 3—peer and lecturer interaction

The desire for more peer interaction is a factor influencing student motivation in online STEM learning. Additionally, interactions with lecturers, such as guidance, are a significant factor in student motivation in online learning (Helmi et al., 2024; Sung and Huang, 2024).

Variable 4—environmental distractions and availability of technologies

These include factors that hinder learning, such as internet issues, limited access to necessary technology and resources, and other distractions. Addressing these challenges is crucial for successful online learning (Quinto et al., 2024).

In summary, these four variables were identified from the included articles as crucial for promoting online learning acceptance from students' perspective. Positive interactions with peers and instructors were strongly linked to higher motivation and engagement in online learning environments (Helmi et al., 2024; Sung and Huang, 2024). However, these studies also showed mixed results regarding peer interactions, with students in highly autonomous learning settings (e.g., self-paced courses) reporting lower satisfaction despite the presence of peer collaboration features. Quinto et al. (2024) suggest that the style of interaction between peer involvement and course structure might influence how students perceive online learning.

Outcome-related variables

These variables relate to the results of the learning process.

Variable 1—satisfaction

Several factors, such as task-technology fit, social presence, and quality of content, influence student satisfaction, which reflects students' overall contentment with their online learning experience (Navarro et al., 2021).

Variable 2—outcome achievement

This refers to the degree to which students achieve the learning objectives of a course, and it is often influenced by online learning strategies. When students achieve a higher level of learning objectives, they have a higher acceptance of online learning (Quinto et al., 2024; Wang et al., 2023).

Variable 3—behavioral intention

This is reflected in a student's willingness to use an online learning platform. Students' perceptions of usefulness and perceived ease of use directly influence behavioral intentions (Luo and Yuan, 2024; Navarro et al., 2021).

Variable 4—academic performance

Students' academic performance serves as an indicator of the impact of online learning technologies on their coursework success (Zogheib, 2024).

In summary, outcomes are an important key component of engineering education. Outcomes like satisfaction, academic performance, and intention to continue using online learning platforms were strongly linked to acceptance. These variables highlight the complex interplay of technological, individual, social, and environmental factors that affect how students and educators adopt and experience online learning in engineering education. However, there was some variance in the factors that influenced satisfaction. Luo and Yuan (2024) found that task-technology fit, and content quality were strong predictors of satisfaction, while others found that student satisfaction could be influenced more heavily by social presence and the perceived supportiveness of instructors (Navarro et al., 2021).

> *RQ3*: How do the identified factors affect the acceptance of online learning and teaching in engineering education, and what do these factors reflect about the importance of the acceptance?

Based on the four identified categories of variables – technology-related, individual-related, social and environmental, and outcome-related – here is how identified factors affect the acceptance of online learning and teaching in engineering education, and what these factors reflect about the importance of that acceptance:

Technology and system design

Technology and system design play an important role in online engineering education. If students do not have access to the required technology, they may face barriers that hinder their acceptance of online learning (Quinto et al., 2024). Students are more inclined to accept online learning when they believe the system enhances their learning performance and efficiency. If a Learning Management System (LMS) is seen as beneficial and relevant, students will be more likely to use it (Zogheib, 2024; Navarro et al., 2021). According to Navarro et al. (2021), the compatibility between the learning management system and learning tasks is a key factor in acceptance. High-quality, relevant, and well-structured content also contributes acceptance and satisfaction (Zogheib, 2024). Li and Liu (2024) found that the specific tools and features available in the online system directly impact adoption, as well as the quality, relevance, and structured content.

Individual differences

Learning is a complex process, and each individual has unique characteristics. These characteristics influence their acceptance of online learning and teaching in engineering education. Based on the included articles, here are some key individual factors that need to be considered while offering online learning in engineering education.

Since online education often requires students to learn at their own pace, students who are prepared for self-directed learning tend to adapt more easily to online learning. This includes being responsible for their learning, having initiative, and managing their time effectively (Watson et al., 2024). Zogheib (2024) stated that higher self-efficacy leads to greater acceptance. A student's confidence in using online learning tools directly affects their attitude and intention to engage with the platform. Both intrinsic and extrinsic motivation play a significant role that impacts students' acceptance of online learning. Sung and Huang (2024) highlight that lecturers' contributions and guidance are important for increasing student motivation during online learning. On the other hand, if online learning increases cognitive load, students may be less accepting (Watson et al., 2024).

Students' skills and competencies also impact their acceptance of online learning. Students with strong time-management skills are more likely to accept and succeed in online learning (Quinto et al., 2024). Flexibility and adaptability to the online learning are also associated with greater acceptance (Sung and Huang, 2024).

Social and environmental interaction

The sense of community and opportunities for interaction in online platforms are important for student satisfaction and acceptance (Navarro et al., 2021). These interactions enhance belonging and engagement, which are important for motivation and positive attitudes toward online learning. However, distractions, poor internet, lack of access to equipment, or an unsupportive learning environment can negatively affect students' acceptance and online learning experience (Navarro et al., 2021). Additionally, Sung and Huang (2024) found that peers' views on technology also influence students' acceptance of online education. Peer influence, particularly in collaborative online environments, can affect how students perceive the effectiveness and benefits of online learning. The interaction between students, peers, and instructors has also been identified as a key factor in shaping students' attitudes toward online learning (Zogheib, 2024). Not only do peers' perspectives matter, but the support and guidance provided by instructors are also significant predictors of students' motivation and their acceptance of online learning. Positive interactions can improve motivation, engagement, and overall learning outcomes (Helmi et al., 2024; Quinto et al., 2024).

Performance and outcome-related

In engineering education, performance and outcomes are very important, as students' future careers depend on their qualifications. The outcomes become key factors in the satisfaction and acceptance of learning online (Zogheib, 2024; Navarro et al., 2021). Satisfaction is correlated with acceptance. Satisfaction is linked to factors such as task-technology fit, social presence, and content. When students are satisfied with their online learning experience, they are more likely to accept it and perform better (Quinto et al., 2024). Luo and Yuan (2024) stated that when students find the LMS useful and easy to use, their intention to keep using it increases, which also is linked with a high level of performance. Additionally, students' perception of academic success as a result of online learning can impact their acceptance of online learning (Zogheib, 2024; Quinto et al., 2024).

In summary, the acceptance of online learning in engineering education is influenced by a range of factors related to technology, individual characteristics, social environment, and learning outcomes. A better acceptance of online learning can make engineering education more accessible, while also helping to develop skills, and preparing students for the future career. Additionally, it allows teachers to improve efficiency and create a better learning environment. Understanding how these factors interact, along with identifying inconsistencies across studies, can help in designing more effective and contextually appropriate online learning experiences.

Discussion

Engineering education is evolving in response to advancements in technology, society, and the global economy. While traditional models of technical training remain foundational, there is increasing emphasis on interdisciplinary, project-based learning, soft skills development, and preparing students to tackle complex, real-world problems. Despite challenges related to retention, diversity, and workforce preparation, innovations in teaching methods, industry collaboration, and technology integration are transforming the field. As engineering education continues to grow, it will be important for institutions to remain agile, continuously adapt to new demands, and provide students with the skills necessary to thrive in a dynamic, interconnected world. Online learning has the potential to play a crucial role in enhancing engineering education.

Our findings address several key factors influencing the acceptance of online learning and teaching in engineering education, emphasizing the elements that contribute to its overall acceptance and the potential for expanding fully online programs. Acceptance is influenced by a variety of factors that can be categorized into technology and system design, individual characteristics, social and environmental factors, and outcome-related factors. Understanding these factors is critical to creating effective, accessible, and engaging online learning environments. These factors are interconnected and collectively influence students' acceptance significantly. Although this review found conflicts regarding the relative importance of the factors, a one-size-fits-all approach is not feasible. Nevertheless, these factors clearly impact the acceptance of online engineering education.

To broader STEM education implications

The findings from this review, particularly the growing acceptance of online learning and the adoption of innovative teaching methods, offer valuable insights that extend beyond engineering and can address challenges in broader STEM education. For example, online labs in fields such as physics and chemistry face similar challenges in creating engaging, interactive experiences for students. Utilizing virtual tools or simulation applications can help solve the challenges of STEM online learning. By designing online learning effectively, it can enhance student engagement and improve retention rates in STEM education. Additionally, online learning opens opportunities to integrate skill development through interdisciplinary collaboration and real-world problem-solving, preparing students for the demands of a rapidly evolving workforce.

For policymakers and other institutions

The review also emphasizes the need for policymakers and educational institutions to integrate various factors when designing online engineering education. The success of online learning in engineering demonstrates how virtual tools and technologies can improve accessibility, flexibility, and student engagement. The technological design of online platforms has an important role, but individual characteristics such as self-efficacy and motivation also significantly impact students' willingness to engage with online learning. Additionally, providing a supportive social environment through peer interaction and lecturer guidance is essential for enhancing student satisfaction and long-term success in online learning.

Educational institutions should focus on creating flexible, adaptive learning environments that deliver the knowledge that students need. It is worth investigating and investing in reliable and scalable virtual platforms for optimal online education outcomes. As online engineering education continues to expand, the role of ABET accreditation also needs to be considered. For online programs, aligning with ABET's rigorous standards is critical to maintaining credibility and ensuring they deliver the same level of education as traditional on-campus programs. This means that online programs need to align with ABET criteria for curriculum, faculty qualifications, student outcomes, and resources, even in virtual settings, to meet the expectations of academia and industry. This alignment assures employers that graduates, regardless of delivery format, are well-prepared for the workforce.

Limitations

One limitation is the limited number of reviewed articles analyzed regarding the factors of online engineering education acceptance and its potential for expanding fully online programs. While the review identified patterns in these factors, the complexity of their influence to the acceptance of online learning needs further research. Future research could focus on examining the interrelationship between these factors, exploring their relative influence and potential conflicts.

Another limitation of this review is the lack of consistency in applying online learning theories to fully online engineering education. Currently, engineering programs primarily follow ABET accreditation standards and guidelines, but there is no adopted online learning theory framework specifically designed for these programs.

Conclusion

This systematic review identified the factors that impact acceptance of online engineering education. Online education empowers educators to increase efficiency and cultivate a sustainable learning environment. This review concluded several findings based on each research question: (1) offering enhanced learning experiences through active engagement, incorporating effective instructional strategies such as learning models, techniques, and student engagement methods to optimize educational outcomes; (2) utilizing tools and platforms, like virtual labs, AI-driven tutoring, and interactive simulations, to help improve academic performance by addressing current limitations and promoting student success; (3) fostering the development of key skills such as self-direction, time management, and technology literacy, which are essential for professional success in engineering fields; (4) accommodating diverse student needs; and (5) providing better lecturer engagement, mentorship, and peer collaboration.

The findings can guide teachers, administrators, and instructional designers in effectively promoting online engineering education. If online engineering programs consider a broad range of interrelated factors, such as technology, individual characteristics, social and environmental elements, and learning outcomes, they may be better equipped to overcome challenges.

Future studies could address key gaps that require deeper exploration: (1) developing an integrated approach that takes into account how these factors interact, and in what contexts they have more or less influence; (2) exploring the development and application of an online learning theory framework that aligns with ABET accreditation standards, ensuring that it supports the unique needs and challenges of fully online engineering education; and (3) evaluating long-term learning outcomes in online engineering education.

Author contributions

Y-PH: Writing – original draft, Writing – review & editing, Data curation, Formal analysis, Funding acquisition, Methodology, Project administration, Resources, Supervision, Validation, Visualization. DC:

Data curation, Writing – review & editing. IK: Data curation, Methodology, Resources, Writing – review & editing.

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