2026 ASEE ANNUAL CONFERENCE June 21–24, 2026 | Charlotte Convention Center, NC

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Paper ID #53553

Why Do We Skip the Theory When We Teach to Save the Planet? A Scoping Literature Review of Learning Theories in Sustainability Engineering Education

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Abstract

This research answers the question: "What learning theories are most frequently applied within sustainability in engineering education literature and to what extent is sustainability education informed by established learning theories?" As sustainability becomes central to engineering practice, integrating sustainability education into engineering curricula is both urgent and complex. Yet, while the content of sustainability education has been widely examined, far less attention has been devoted to the learning theories that shape its delivery. This gap limits the field's ability to design pedagogies that not only convey sustainability knowledge but also cultivate the deeper cognitive, reflective, and action-oriented capacities required for engineers to address contemporary sustainability challenges.

Using a scoping literature review, this study collects and analyzes peer-reviewed articles from academic databases including Compendex, INSPEC, Scopus, and ERIC. Studies are selected based on their focus on sustainability education in engineering and explicit reference to learning theories such as constructivism, experiential learning, transformative learning, or social learning. The findings indicate a growing incorporation of learning theory in sustainability teaching within engineering education, with approximately 76% of the studies included in this review published in 2019 or later explicitly grounding their work in a learning theory. Both constructivism and transformative learning theory featured prominently. However, some studies lacked clarity or consistency in articulating the learning theories guiding their instructional design, student learning processes, or research framing.

The findings of this study offer valuable guidance for engineering educators engaged in sustainability education by supporting more intentional pedagogical choices. Deliberately integrating learning theory into curriculum design enhances educational effectiveness, fosters deeper learning outcomes, and aligns instruction with the interdisciplinary and values-driven nature of sustainability challenges.

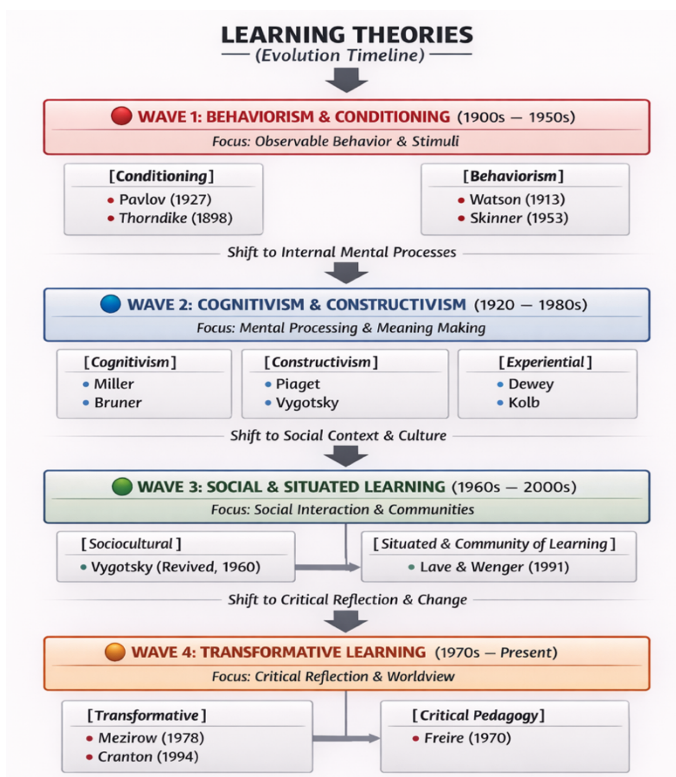
Keywords: Sustainability, Learning Theories, Engineering Education

1. Background

Engineering has been taught and learned successfully for centuries across the world, yet engineering education as a distinct academic unit, field of research, and practice is still relatively young, barely in its third decade of formal development in the United States [1], [2]. As a result, scholars have worked intentionally to situate the field within established research traditions while also articulating what makes engineering education unique. One major strand of this effort has involved adopting, adapting, and applying foundational learning theories originally developed in non-engineering disciplines, such as psychology, education, and the learning sciences, to the study of how engineers are educated [3], [4]. Reviewing these theories, identifying best practices, and translating them for engineering contexts is therefore a valuable contribution to the broader engineering education community.

Sustainability sits at the intersection of social, environmental, economic, ethical, and interdisciplinary discourses. Educators have used this multidimensional construct not only to teach responsible engineering practice but also to examine how students develop interdisciplinary skills. Given this complexity, grounding sustainability education in learning theory is essential [5]; without it, we cannot meaningfully understand, or replicate, the processes through which students develop the interdisciplinary capacities the field demands [6], [7]. Learning theories form a critical foundation for examining educational practice [3]. These theories provide conceptual frameworks that enhance pedagogical practice, guide evidence-based instructional design, and improve educational outcomes [8], [9]. Among the most enduring learning frameworks are behaviorism, cognitivism, and constructivism [10], [11], [12].

For the purpose of this study, I have organized learning theories into a series of "waves." The first wave comprises foundational behaviorist theories, including classical and operant conditioning. The second wave introduces cognitive, constructivist, and experiential perspectives that shifted attention from observable behavior to internal mental processes and learner-centered meaning-making. The third wave encompasses sociocultural theory and situated learning, emphasizing the social, cultural, and contextual nature of learning. The most recent wave includes transformative learning and other emerging perspectives that extend earlier theories or respond to new educational challenges (Figure 1). Together, these waves illustrate the evolving landscape of learning



theory and the increasing complexity with which scholars conceptualize how people learn. Note: Some theories are dated, while others are not. Because several theoretical traditions emerged over overlapping periods and lack clear historical boundaries, certain dates are intentionally left open for this paper.

2. Brief History of Sustainability

Although the idea of sustainable development is widely circulated, the definition of sustainability itself is far less straightforward. In practice, common searches for "sustainability" often return the Brundtland definition of sustainable development, and the concept is frequently framed narrowly through environmental or natural-resource lenses [13]. Only in recent years have engineering institutions such as the Accreditation Board for Engineering and Technology (ABET) [14] and several engineering education scholars begun to operationalize sustainability, clarifying its intended outcomes within engineering education; for example, see Table 1 for several operationalized definitions of sustainability.

While these definitions are discussed in later paragraphs, the present section traces the historical development of sustainable development, from its early roots in ecological awareness and resource management to key milestones culminating in the Brundtland Report [13], which framed sustainable development as "development that meets present needs without compromising the ability of future generations to meet their own needs" [15, p.15] This historical trajectory illustrates how sustainability education, as we know it today, has evolved from an initial focus on development, natural resources, and environmental concerns into an interdisciplinary framework of competencies necessary to address complex challenges that extend far beyond any single domain.

To situate this evolution within a wider historical context, it is also important to recognize that the idea of sustainable development has precursors across Africa, the Americas, and Europe. In Africa, the African Convention on the Conservation of Nature and Natural Resources, adopted in Algiers in 1968 and entering into force in 1969, established one of the earliest continent-wide commitments to environmental stewardship [16]. Importantly, the African and American milestones unfolded almost concurrently.

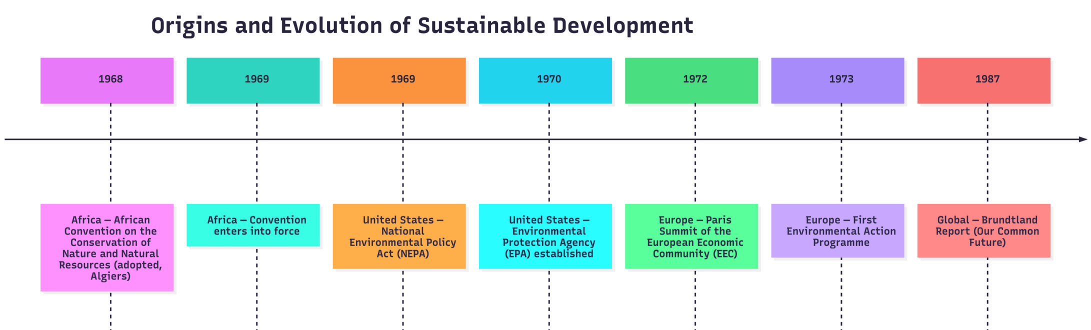


Figure 1: Historical Evolution of Sustainable Development in Africa, the Americas, and Europe

In the United States, the passage of the National Environmental Policy Act (NEPA) in 1969 and the creation of the Environmental Protection Agency in 1970 marked a significant shift toward formalized environmental governance, influencing global policy discourse [17], [18]. Europe began developing a coordinated environmental policy slightly later; at the Paris Summit of the European Economic Community in October 1972, heads of state formally recognized the need for a common environmental policy and called for the development of an action programme. This declaration is widely regarded as the beginning of EU-level environmental policy, followed by the adoption of the First Environmental Action Programme in 1973 [19]. Together, these developments helped lay the groundwork for the global consensus later articulated in Our Common Future (the 1987 Brundtland Report).

2.1. How has engineering education defined sustainability?

Definitions of sustainability in engineering education largely depend on disciplinary orientation and contextual perspectives. For instance, scholars who adopt an environmental perspective tend to frame sustainability as an ecological or environmental concern. Those emphasizing the social dimension interpret sustainability as a social responsibility or equity issue [20], while others who focus on the economic pillar view it as an issue of resource efficiency and long-term economic viability. Some scholars simply adopt the UN definition of sustainable development, while others operationalize the definition of education for sustainable development [21]. I present a few operationalized definitions of sustainability within the engineering education community, broadly grouped into two main categories: one, definitions from accreditation and engineering societies; and two, definitions from academic literature reported in Table 1.

ABET operationalizes sustainability as a program outcome, specifying the knowledge, skills, and attributes students are expected to demonstrate upon completing an ABET-accredited engineering degree. The Engineering for One Planet framework similarly defines sustainability as an academic outcome, but places stronger emphasis on the intentional integration of sustainability-related units throughout the curriculum to achieve that outcome. In contrast, the American Society of Civil Engineers conceptualizes sustainability as the ongoing opportunity to create solutions that maintain quality of life indefinitely. Across the scholarly literature, sustainability is most often operationalized as a set of competencies that prepare engineering graduates to adopt and apply sustainable practices in professional contexts.

Table 1

Definition of Sustainability Within Engineering Education Across Professional Societies and Scholarship

Accreditation or Engineering Society & Academic Scholarship	Definition of sustainability	Source
ABET (Accreditation Board for Engineering and Technology)	[The ability] to *apply* engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, *social, environmental, and economic factors*. [An ability] to *recognize* ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, *economic, environmental, and societal contexts*.	ABET Criterion 3 (Student Outcomes 3 & 4). ABET [14]
Engineering for One Planet (EOP) framework	Designs, practices, innovations, technologies, methodologies, etc., that mitigate negative impacts and/or enable increased positive and regenerative impacts on environmental and social systems.	EOP framework focused learning outcomes for engineering education, page 3 [22]
The American Society of Civil Engineers (ASCE)	Defines sustainability as a set of environmental, social, and economic conditions (aka "The Triple Bottom Line") in which all of society has the capacity and opportunity to maintain and improve its quality of life indefinitely without degrading the quantity, quality, or the availability of environmental, social, and economic resources.	ASCE [23]
National Academy of Engineering	Drawing on the Brundtland Commission's definition of sustainability, the National Academies frame sustainability in engineering as a systems- and life-cycle-oriented practice, articulated through green engineering principles that guide the design of processes and technologies toward reduced risk, resource efficiency, and long-term societal benefit.	NAE [24]
Academic Literature	Engineering education sustainability is the incorporation of environmental, social, and economic aspects into the education of future engineers... with the focus on creating solutions that address current technical and economic needs as well as sustain long-term ecological equilibrium and social welfare	Arefin [25] Sabri [26] Quelhas [27]

3. Method

This study aims to answer whether sustainability education is grounded in established learning theories and examines which theories are most prevalent in the literature. Accordingly, the guiding research question is: To what extent is sustainability education informed by established learning theories, and which learning theories are most frequently applied within the existing literature? A scoping review approach was selected in recognition that sustainability education is a broad, conceptually diverse, and unevenly developed field that encompasses a wide range of domains and perspectives [28], [29]. This breadth and diversity reflect the field's expansive nature. At the same time, educational theories are applied differently, and sometimes inconsistently, across these domains, making it necessary to map how theories have been taken up rather than to evaluate the quality or effectiveness of individual studies [30], [31]. A scoping review is therefore appropriate, as it is designed to chart the extent, range, and nature of existing research rather than to judge or compare outcomes [30].

3.1.Protocols

The study followed an a priori protocol consisting of a two-stage selection process. First, a comprehensive dataset was compiled by systematically searching relevant databases [31], [32], [33] using predefined keywords related to engineering education and sustainability, yielding an initial corpus of studies. Second, this larger dataset was narrowed using a priori inclusion and exclusion criteria [30], [33] to identify studies explicitly focused on sustainability in engineering education. This protocol decision was informed by a scoping review protocol grounded in the PRISMA extension for Scoping Reviews (PRISMA-ScR [31]), alongside established scoping review best-practice articles articulated by Arksey and O'Malley [30], Phillips et al. [34], and Munn et al. [33].

3.2. Eligibility Criteria

Inclusion criteria

To qualify for inclusion in this study, documents were required to satisfy all of the following conditions:

1. Publication type: The document must be a journal article or conference paper. Conference papers were included because, within engineering education research, it is common practice to present and disseminate peer-reviewed scholarly work at conferences.
2. Language: The document's full text must be in English.
3. Topical focus: The document explicitly addressed (i) sustainability (environmental, economic, social, and/or ethical dimensions) and (ii) learning theories or a clearly established framework within an engineering education context (for undergraduate and occasionally graduate students).

4. Educational context: The study examined sustainability in engineering teaching and learning, including but not limited to curriculum design, instructional strategies, course modules, pedagogical interventions, and student learning outcomes.

Exclusion criteria

1. Publication type: Studies published as book chapters, dissertations, theses, or other non–peer-reviewed sources were excluded. This decision reflects prevailing dissemination norms in engineering education research, where journal articles and conference proceedings constitute the primary scholarly outlets.
2. Language: Studies whose full text was not available in English were excluded due to feasibility constraints related to translation and analysis.
3. Publication status: Preprint articles and conference papers labeled as works in progress were excluded due to their preliminary status and the potential for substantive changes following peer review.
4. Topical and theoretical scope: Studies were excluded if they did not address sustainability within an engineering context or did not explicitly frame the study within a learning theory or an established conceptual or theoretical framework from which theoretical assumptions could be reasonably inferred.

3.3. Information Sources and Search Strategy

I designed and conducted the initial search strategy. After preliminary search results were obtained, I consulted with an experienced engineering education librarian at a large public research university. Search strings and preliminary research questions were shared with the librarian, and feedback was incorporated to refine the search strategy. For this study the databases searched included Compendex (via the Engineering Village platform) and INSPEC (via the Engineering Village platform). Based on the librarian's recommendations, the search was expanded to include Scopus. These databases were selected due to their strong emphasis on engineering literature and their broad coverage of engineering subject areas.

As part of a larger study on sustainability and environmental engineering education, the initial search was conducted during the week of July 19, 2024, followed by an updated search on August 27, 2024. A final search update was conducted on January 16, 2026, at which time the ERIC database (via EBSCOhost) was added to broaden coverage of sustainability-focused literature. While this approach prioritized engineering-focused scholarship, it is acknowledged that some relevant studies may not have been captured, particularly those published in more specialized disciplinary repositories. The reason repositories were not included in this study was to avoid an overrepresentation of conference papers, as it is the researchers' understanding that most conference papers within sustainability engineering education, although peer reviewed, do not clearly emphasize the use of theory. This is also evident in the results of the present study.

The conceptual search string for this review is added below, while the search string per data base is added in the appendix

(engineering education for sustainability" OR "engineering education and sustainability" OR "education for sustainable development" OR ESD) AND ("engineering education" OR "engineering students" OR "engineering curriculum") AND ("higher education" OR undergraduate OR "tertiary education") AND ("learning theory" OR "learning theories" OR pedagogy OR "pedagogical framework" OR constructivism OR "social constructivism" OR "experiential learning" OR "transformative learning" OR "problem-based learning" OR "project-based learning).

3.4.Title and abstract review

Each retrieved article was screened against the predefined inclusion criteria [31], [32]. During the initial screening stage, article titles, abstracts, and author-provided keywords were reviewed to determine relevance. Articles whose titles, abstracts, or keywords did not include concepts aligned with the predefined search terms were excluded at this stage. Abstracts of the remaining records were then reviewed in greater detail to determine whether each study met the full inclusion criteria before full-text review.

3.5.Full-text review

In the first stage, I screened the literature reviews and methods sections of the selected texts to identify whether and how theory was used to support the study. Following this review, I conducted keyword searches within each text to identify references to learning-theory-related terms commonly used in the sustainability and engineering education literature (e.g., constructivism, experiential learning, situated learning, trans/interdisciplinary, and transformative learning). In the second stage, I conducted a detailed, close reading of the relevant sections of each article. During this stage, I focused on the methods, theoretical justification, and analytic framing, with particular attention to how theory was used to guide educational practice, research inquiry, and interpretation of results.

4. Results and Discussion

4.1 Analysis

This study examined “What learning theories are most frequently applied within sustainability in engineering education literature and to what extent is sustainability education informed by established learning theories?” To obtain the data necessary to address the research questions, I followed the PRISMA flow diagram for scoping reviews as a guiding framework [32]. PRISMA is a structured reporting framework that supports transparent and systematic documentation of study selection processes [31], [32], [34]. This approach structured the identification, screening, eligibility assessment, and final inclusion of sources within this subset of the engineering education literature. The decision to use PRISMA was based on its emphasis on rigor and transparency, and it has also been widely used in related engineering education research [30],

[33], [34], [35]. The resulting selection formed the basis of the dataset used for analysis in this study reported in figure 3.

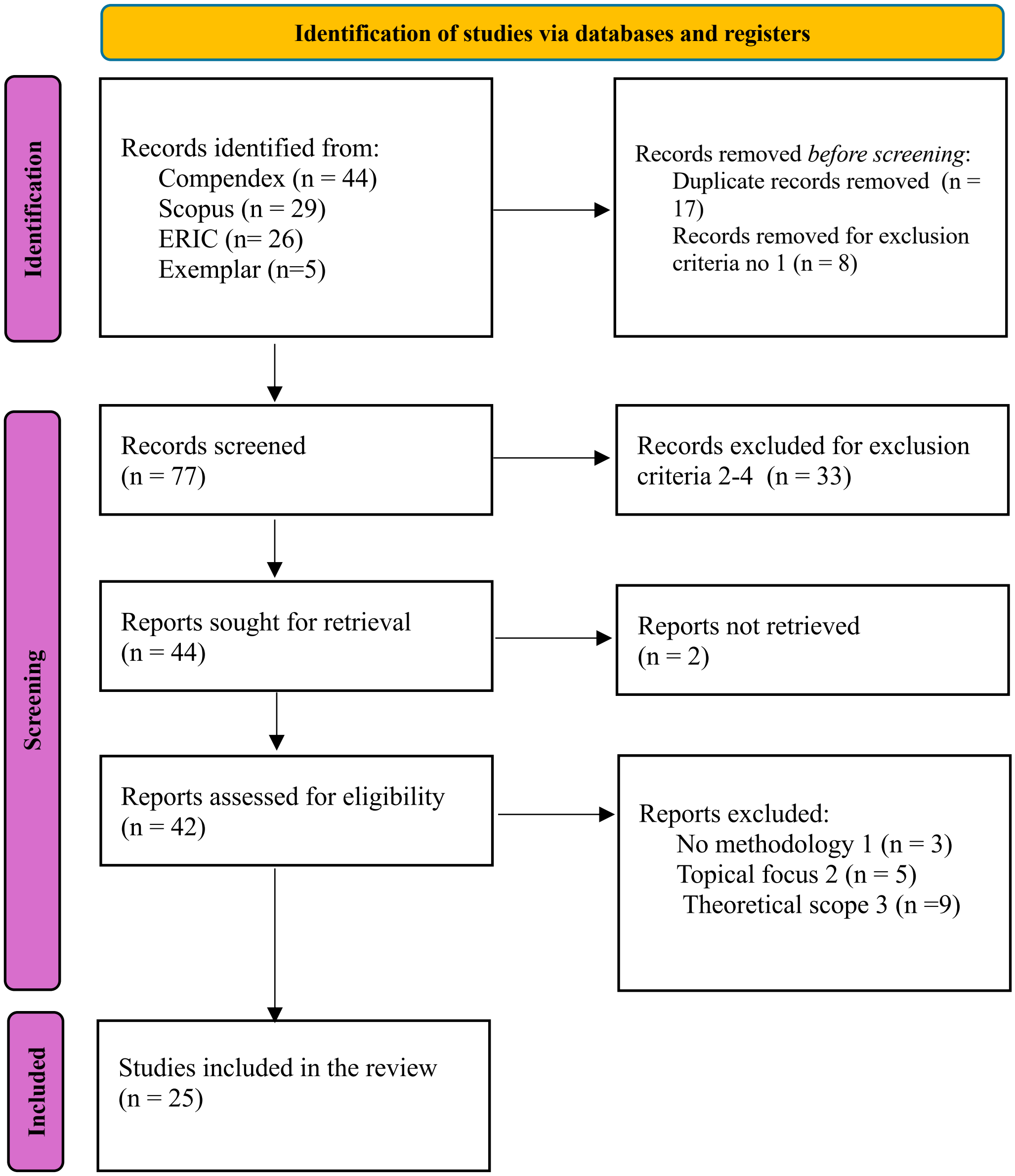


Figure 3. PRISMA flow diagram for this scoping review. Source: Adapted from Page et al. [32].

Research Question 1: "What learning theories are most frequently applied within sustainability in engineering education literature. To answer the first research question on the frequency of theoretical orientations in the study, I used an Excel spreadsheet to identify the authors, year of publication, article type, and theoretical orientation, as reported in Table 2. This provided the preliminary data used to generate the frequency of theoretical orientations present in the dataset, as reported in Figure 4.

Table 2
Overview of Included Studies by Author, Year, Paper Type, and Theoretical Orientation

Year	Author	Paper Type	Theoretical Orientation
2024	Sagaris, et al	Article	Critical Pedagogy
2012	Missimer & Connell	Article	Constructivism
2018	Berdanier et al.	Article	Constructivism
2024	Habash	Article	Constructivism
2005	Paten, et al	Article	Critical Literacy
2012	Yusof, et al	Article	Cooperative Problem-Based Learning
2017	Guerra	Article	Problem Based Learning
2008	Tomkinson, et al	Article	Problem Based Learning
2025	Tshikolu, et al	Article	Problem Based Learning
2012	Dobson & Tomkinson	Article	Problem Based Learning
2024	d'Escoffier, et al	Article	Problem Based Learning
2015	Fernandez-Sanchez, et al	Article	Problem Based Learning
2024	Kayi	Article	Transformative Learning Theory
2023	Heddy, et al	Article	Transformative Experience
2022	Khandakar, et al	Article	Project-Based Learning
2023	Ariza & Olatunde-Aiyedun	Article	Project-Based Learning
2019	Malheiro, et al	Article	Project-Based Learning
2017	Hedden, et al	Article	Project-Based Learning
2024	Shinde	Conference	Project-Based Learning
2024	Doss, et al	Conference	Problem Based Learning
2023	Laka, et al	Conference	Project-Based Learning
2024	Senderos et al	Conference	Project-Based Learning
2022	Karampa & Paraskeva	Conference	Project-Based Learning
2013	Briede	Conference	Constructivism
2023	Mehta, et al	Conference	Transformative Learning Theory

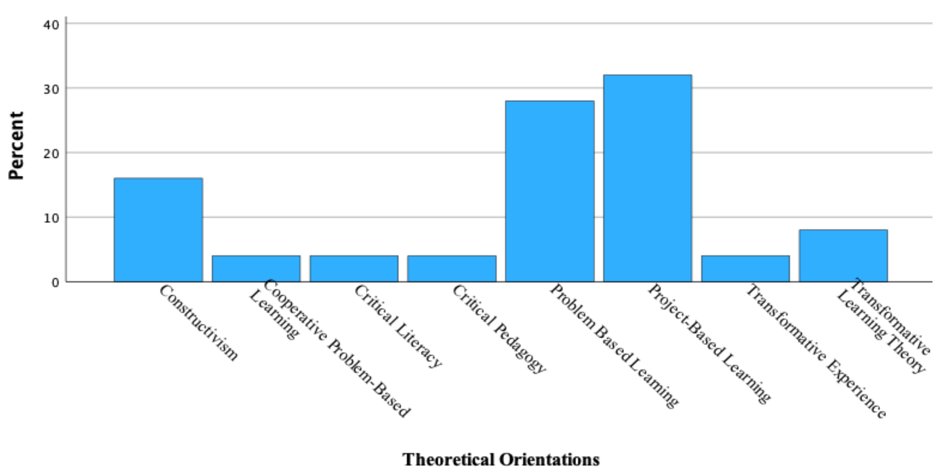


Figure 4: Frequency Distribution Theoretical Orientations in the Reviewed Studies

Research Question 2

The first research question provides the basic descriptive statistics that inform the second research question: “To what extent is sustainability education informed by established learning theories?” To answer this question, I first examined the studies in which learning theories were explicitly mentioned. Out of the total 25 publications that met the inclusion criteria for this review, 18 were classified as journal articles and 7 as conference papers. Journal articles represented the majority of the sample and accounted for the primary venue through which research on this topic is disseminated. However, only seven of the 18 journal articles explicitly mentioned a learning theory, with constructivism cited four times, transformative learning theory cited twice, and critical pedagogy and critical literacy each cited once. Conference papers contributed a smaller, but still meaningful, portion of the literature, with constructivism and transformative learning theory each mentioned once (Table 2).

In addition to explicitly named learning theories, several studies referenced pedagogical approaches commonly associated with constructivist traditions. Within the journal articles, problem-based learning (PBL) was mentioned seven times and project-based learning (PjBL) four times. In the conference papers, PjBL appeared four times, while PBL was mentioned once. Although PBL and PjBL are not always framed as formal learning theories, they are deeply rooted in constructivist assumptions and often draw on a wider constellation of theoretical perspectives that emphasize active, social, reflective, and authentic learning. Consequently, even when authors did not explicitly cite a learning theory, the pedagogical choices they described implicitly align with traditions such as constructivism, social constructivism, and experiential learning for example Yusof et al [36], Tshikolu, et al [37] and Doss, et al [38].

4.2 Discussion

Overall, the findings indicate a growing incorporation of learning theory in sustainability teaching within engineering education, with approximately 76% of the studies included in this review published in 2019 or later explicitly grounding their work in a learning theory. However, some studies lacked clarity or consistency in articulating the learning theories guiding their instructional design, student learning processes, or research framing. In response to these patterns, this discussion advances the case for the continued and more explicit use of learning theory in sustainability education within engineering education, emphasizing its importance for ensuring coherence, rigor, and long-term educational impact.

Continuing learning theory is essential in engineering education because engineering practice evolves faster than static curricula. Rapid technological change, complex socio-technical systems, sustainability challenges, and ethical responsibility require engineers who can continuously learn, unlearn, and relearn throughout their careers. In this context, continuing learning theory supports the cultivation of lifelong learning habits, enabling engineers to integrate new knowledge, respond to uncertainty, and make responsible decisions in dynamic professional environments. This emphasis aligns with professional expectations articulated by bodies such as ABET [14], which stress ethical responsibility, teamwork, problem-solving, and the ability to acquire new knowledge as core outcomes of engineering programs.

Learning theories provide conceptual frameworks that strengthen teaching and learning processes while fostering key sustainability competencies. These theories guide educators in designing curricula that not only transmit knowledge but also promote critical thinking, reflection, collaboration, and active engagement with complex sustainability challenges. For example, transformative learning theory emphasizes critical reflection and dialogue as mechanisms for deep learning that can lead to personal and societal change, making it particularly relevant for sustainability education, where learners must grapple with uncertainty, values, and systemic change [7], [39].

Similarly, constructivist learning theories create opportunities for learners to collaboratively construct knowledge around social and environmental problems that are often ill-structured and "messy" [40], [41]. Approaches grounded in constructivism, such as problem-based learning, have demonstrated effectiveness in engaging students with sustainability topics by making learning interactive, context-connected, and reflective, while encouraging learners to critically examine their roles, responsibilities, and decision-making within socio-environmental systems.

Limitations

Although the scoping review protocol was followed with care, the search strategy and database selection would benefit from further expansion. In particular, incorporating additional sources, such as the ASEE PEER, IEEE Xplore repositories, Web of Science, and relevant grey literature (e.g., technical reports, dissertations, and institutional publications), could enhance the comprehensiveness of the review. Grey literature is often difficult to systematically locate, yet it often contains richer descriptions of theoretical frameworks, more explicit accounts of how learning theories are operationalized, and detailed applications in sustainability education contexts. Including these sources would therefore enhance the review's ability to capture the full landscape of how learning theories are being used, adapted, and extended in sustainability-focused engineering education research.

Another limitation of this review concerns the interpretive challenges associated with identifying and classifying learning theories within the included studies. Some publications in this study did not explicitly name a learning theory, requiring inferences based on pedagogical descriptions such as problem-based learning, project-based learning, or experiential activities. While these approaches are commonly associated with constructivist or experiential learning traditions, attributing theoretical orientation based solely on pedagogical design risks over-interpretation. Authors may employ these methods pragmatically rather than theoretically, and the absence of explicit theoretical grounding limits the certainty with which theoretical alignment can be assigned.

Additionally, the variability in how learning theories were described or omitted across publication types introduces interpretive ambiguity. Journal articles tended to provide more explicit theoretical framing than conference papers, but even within journals, theories were inconsistent and sometimes only superficially integrated. This inconsistency makes it difficult to determine whether the limited presence of theory reflects actual practice in sustainability-focused engineering education or simply inconsistent reporting practices.

Conclusion

This scoping literature review examined how learning theories are used to support sustainability education within the engineering education context. Sustainability education offers students opportunities to engage in conscientious engineering practice while developing the interdisciplinary competencies required to address complex global challenges. Given this renewed emphasis, the need to ground both curriculum design and research in robust learning theories cannot be overstated. Such theories provide a framework that enables researchers and practitioners to replicate effective approaches, adapt them to their own contexts, and report evidence aligned with best practices. The review revealed that constructivism, transformative learning theory, and experiential learning theory are among the most frequently applied theoretical frameworks in sustainability-focused engineering education. Correspondingly, problem-based and project-based learning emerged as the dominant pedagogical approaches for operationalizing these theories. These findings can help educators make more intentional pedagogical choices and guide future research in sustainability engineering education by highlighting the theoretical and instructional foundations that currently shape the field.

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Appendix: Database Search String Used in the Study

A: Scopus

("engineering education for sustainability"

OR "engineering education and sustainability"

OR "education for sustainable development"

OR ESD)

AND ("engineering education"

OR "engineering students"

OR "engineering curriculum")

AND ("higher education"

OR undergraduate

OR "tertiary education")

AND ("learning theory"

OR "learning theories"

OR pedagogy

OR "pedagogical framework"

OR constructivism

OR "social constructivism"

OR "experiential learning"

OR "transformative learning"

OR "problem-based learning"

OR "project-based learning"))

B: ERIC

(AB:("engineering education for sustainability" OR "engineering education and sustainability"

OR "education for sustainable development" OR ESD)

AND AB:("engineering education" OR "engineering students" OR "engineering curriculum")

AND AB:("higher education" OR undergraduate OR "tertiary education")

AND AB:("learning theory" OR "learning theories" OR pedagogy OR "pedagogical framework"

OR constructivism OR "social constructivism" OR "experiential learning"

OR "transformative learning" OR "problem-based learning" OR "project-based learning"))

C: Compendex

("engineering education for sustainability" OR "engineering education and sustainability"
OR "education for sustainable development" OR ESD)
AND ("engineering education" OR "engineering students" OR "engineering curriculum")
AND ("higher education" OR undergraduate OR "tertiary education")
AND ("learning theory" OR "learning theories" OR pedagogy OR "pedagogical framework"
OR constructivism OR "social constructivism" OR "experiential learning"
OR "transformative learning" OR "problem-based learning" OR "project-based learning"))