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Rethinking sustainability in engineering education: a call for systemic change

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The integration of engineering education with sustainability is a major requirement in overcoming global environmental, social, and economic challenges. The educational approach, however, has not been adequate because it differs or varies from one to another. The article identifies key barriers to the effective teaching and learning of sustainability such as persistence of traditional technical paradigms, lack of interdisciplinary engagement, reluctance to curricular changes, and poor practical exposure. On top of this are the new initiatives such as the accreditation standards, project-based learning, and industry partnership. They have shown a promise toward further enhancement, yet they are still being adopted inconsistently. We take the argument that systemic transformation is needed so that sustainability becomes a fundamental principle of engineering, not just one of its electives. To this discipleship transition, there should be incorporated cross-disciplining curriculum, experiential learning models, and strengthened university-industry collaboration, plus emerging digital technologies. This whole-faculty integrated model will help educates future engineers in a manner that can interpret sustainability challenges and produce positive impacts in their practice.

KEYWORDS

sustainability in engineering education, interdisciplinary learning, project-based learning, curriculum reform, engineering ethics, systems thinking, sustainable development

1 Introduction

Engineering education sustainability is the incorporation of environmental, social, and economic aspects into the education of future engineers (Arefin et al., 2021). It focuses on creating solutions that address current technical and economic needs as well as sustain long-term ecological equilibrium and social welfare (Quelhas et al., 2019). Since engineering fields inform much of the built world and industrial operations, integrating sustainability into curricula is critical to producing engineers capable of meeting global issues like climate change, resource loss, and ethics in development (Shields et al., 2014; Theis et al., 2008).

The sense of urgency that drives sustainability in engineering is motivated by a number of interrelated crises. Global climate change has heightened the call for engineers to construct adaptive and resilient infrastructure, create renewable energy systems, and reduce carbon emissions (Fenner et al., 2014). The depleting resources of earth require the application of circular economy concepts so that materials and energy are utilized optimally with waste reduction (Venugopal and Kour, 2020; Yosie, 2014). Ethical obligations in engineering require engineers to think in the long term about the social and environmental impacts of their work, and alongside technical practicability and financial feasibility, prioritize sustainability (Mares-Nasarre et al., 2023).

Nonetheless, it is about the emergence of several frameworks for engineering education toward sustainability. The United Nations Sustainable Development Goals (SDGs) push higher education institutions to align their programs with the global sustainability agenda (Sandanayake et al., 2022). Although accreditation bodies like ABET (Accreditation Board for Engineering and Technology) and sustainability frameworks such as LEED (Leadership in Energy and Environmental Design) and Envision have established comprehensive guidelines to embed sustainability into engineering practice (Theis et al., 2008; Zizka et al., 2021), sustainability remains insufficiently integrated into engineering education. In many academic institutions, it is still approached as a supplementary topic rather than being fully incorporated as a fundamental aspect of the curriculum (Kevern, 2010; Jørgensen et al., 2013).

This paper contends that current efforts to mainstream sustainability in engineering education are fragmented and inadequate. To effectively address the complex challenges of sustainability, engineers must undergo a paradigm shift in their training. This transformation requires moving beyond traditional disciplinary boundaries, fostering interdisciplinary collaboration, and adopting experiential, project-based learning approaches that reflect real-world sustainability issues.

2 Challenges in integrating sustainability in engineering education

In spite of growing acknowledgment of the significance of sustainability in engineering, its incorporation into curricula continues to be a considerable challenge (Guerra, 2017). Conventional engineering education has traditionally been centered on technical problem-solving with minimal consideration of the wider environmental, social, and economic aspects that sustainability requires (Thürer et al., 2018). This section discusses main barriers to the successful incorporation of sustainability in engineering education, such as outdated paradigms, absence of interdisciplinarity, opposition to curriculum change, and insufficient practical exposure.

2.1 Traditional engineering paradigms: the technical vs. holistic approach

Engineers' education has pursued skill in technicality, problem-solving, and efficiency-oriented methodology for a long time (Hadgraft and Kolmos, 2020). Most engineering programs follow the dominant paradigm which leads students to apply the principles of mathematics and science to solve discrete, well-structured problems. Sustainability issues concerning climate change mitigation, energy transition, and sustainable urban planning are indeed complexly intertwined and often involve uncertainty (Lu, 2014; Zizka et al., 2021).

The reductionist approach is found to be inadequate in accommodating sustainability, which indeed requires the ability to holistically look at and discuss environment, economy and society (Sigahi et al., 2022). Traditional engineering education has long emphasized technical competencies such as structural integrity, energy efficiency, and functional performance, often at the expense of broader sustainability considerations. However, contemporary engineers are increasingly expected to assess long-term environmental impacts, lifecycle costs, and engage with diverse stakeholders, skills that are still insufficiently represented in many academic programs (Fenner et al., 2014). This disconnect underscores the urgent need to evolve pedagogical approaches beyond narrowly focused technical training. The absence of systems thinking from much of the curriculum hampers students' ability to address sustainability problems in a relevant way.

2.2 Lack of interdisciplinary integration: the siloed nature of engineering education

Sustainability demands a qualitative and interdisciplinary collaboration to allow for the integration of different knowledge for more sustainable solutions; yet engineering programs are still mostly specialized and compartmentalized (Shields et al., 2014). For example, civil engineers are concerned with infrastructure, electrical and mechanical engineers with energy systems, while chemical engineers are concerned with industrial processes and very little interaction occurs between these disciplines. Please note that these sustainable solutions are not limited to, but include green building design, carbon-neutral manufacturing, and climate adaptation strategies-and these draw input from environmental science, social sciences, economics, and policy studies (Arefin et al., 2021; Theis et al., 2008).

Despite the inclusion of some sustainability-oriented content, most engineering curricula still lack comprehensive systems-thinking approaches (McWhirter and Shealy, 2018). While engineering curricula recognize the trade-offs involved in balancing technical, economic, and environmental factors, they tend to disproportionately emphasize technical viability (Nazzal et al., 2015). In such programs, students fail to gain the wider perspective germane to solving sustainability questions in practice.

2.3 Resistance to curricular change: institutional and faculty constraints

Efforts to adapt engineering curricula by embedding sustainability as a core principle continue to face institutional inertia and faculty resistance (Roure et al., 2018). Key challenges include:

- Bounded accreditation requirements: organizations such as ABET and all such national accreditation organizations have laid specific lines of stringent requirements for engineering programs. Hence, there is no flexibility in the curriculum for the addition of content related to sustainability, which is considered a subtopic rather than an important part of the engineering competencies (Burke et al., 2018; Theis et al., 2008).
- Inaccessibility and ignorance of training by faculty: many of the engineering faculty members trained in conventional

technical fields lack exposure to concepts of sustainability. Hence, they may not be knowledgeable or willing to retake some courses and make those courses available for meaningful integration of sustainability issues of content into teaching practices (Burke et al., 2018; Lu, 2014).

- Perceptions of burden in engineering curricula: more already face such weightiness in mathematics and physics, as well as core technical subjects. Faculty, therefore, hesitate to introduce additional course material to include even a fraction of sustainability-focused content for fear that they would "soften" the technical rigor (Hadgraft and Kolmos, 2020; Shields et al., 2014).

Collectively, this further emphasizes the understanding that sustainability becomes an optional elective or an addon type of course approach and not a core tenet of engineering education.

2.4 Limited practical exposure: the gap between theory and application

While sustainability is gaining a foothold in engineering programs, its inclusion is often limited to theoretical instruction rather than practical application (Hadgraft and Kolmos, 2020). Many courses rely heavily on lectures and case studies to convey sustainability concepts, which, though informative, fall short of offering students meaningful, hands-on experience in designing and implementing real-world sustainable engineering solutions.

There are three main markings in this gap: project-based learning deficits, weak industry collaboration, and minimal engagement of policy and social dimensions.

- Project-based learning is underutilized. Indeed, active learning approaches such as having engineering students design energy-efficient houses, conduct life-cycle assessments, or participate in renewable energy projects, are rarely incorporated into coursework. Most programs fail to integrate these real-world sustainability challenges (Mares-Nasarre et al., 2023).
- Deficient collaboration with industry: the engineering curricula hardly ever engage with industrial partnerships concerned with sustainability-related projects. Career internships are not widespread when it comes to green engineering, low-carbon technologies, and circular economy focus (Brown et al., 2014).
- Minimal engagement with policy and social dimensions: sustainability policies include decisions, stakeholder engagements, and social implications, yet they are rarely part of the training that an engineer will receive concerning environmental policies, community engagement, or regulations (Sigahi et al., 2022).

These issues prove that there needs to be a total transformation in mindset-the mentality with which sustainability is woven into engineering education, the form that teaching takes, and the institutional framework through which this is done. Indeed, beyond the technocratic reductionism, interdisciplinary teamwork; resistance to curricular designs; and experiential formats of delving into sustainability must be overcome if engineers are to be equipped to address real-world problems of sustainability-crossover.

3 Current approaches and their limitations

Reacting to the increasing demand for sustainability in engineering, different initiatives and frameworks have been established to incorporate sustainability into curricula. These are intended to enable engineers to develop environmentally friendly and socially acceptable solutions. Despite to these developments, sustainability education in engineering continues to be fragmented with different sets of integration levels within disciplines and institutions (Arefin et al., 2021; Theis et al., 2008). While some universities have managed to incorporate sustainability into their mainstream programs, others continue to treat it as an elective or add-on component rather than a fundamental engineering principle (Fenner et al., 2014).

While many universities have begun integrating sustainability into their curricula, these efforts often focus on isolated content inclusion, such as counting the number of courses mentioning sustainability, rather than developing key competencies or assessing actual impact. Furthermore, current monitoring and evaluation practices tend to rely on easily measurable indicators rather than reflective, participatory processes that support deeper engagement with education for sustainable development (White et al., 2017).

A common method applied is the LEED (Leadership in Energy and Environmental Design) system, a standard for sustainable building design (Kevern, 2010). LEED certification standards are presented in the majority of engineering programs, with a focus on energy efficiency, material selection, and reducing environmental footprint. Its use is, however, mostly confined to civil and architectural engineering, and the rest of the engineering fields lack any systemic approach to sustainability (Jung et al., 2019). Likewise, the Envision system, which aims at sustainable infrastructure development, offers engineers the means to measure the long-term environmental, economic, and social effects of their projects. Although highly promising, Envision is not widely used in academic practice and is unknown to most engineering students (McWhirter and Shealy, 2018).

Aside from certification-driven models, PBL (Problem Based Learning) has been used to embed sustainability in engineering education by several schools. PBL involves learners in coming up with solutions for real-world sustainability problems, and thus they end up designing viable solutions for problems related to renewable energy, waste management, and clean transportation (Quelhas et al., 2019). PBL-centered programs have managed to verify that learning-by-doing reinforces the capacity of students to employ sustainability principles in real life. Yet, such experiences are not the norm, and students generally graduate having had no exposure to sustainability-oriented projects (Lu, 2014). While CDIO (Conceive-Design-Implement-Operate) offers an engineering education framework that promotes holistic problem-solving, sustainability is not necessarily foregrounded, leaving its delivery to individual faculty initiative and institutional priority (Guerra, 2017).

Regional attempts at integrating sustainability into engineering curricula are disjointed. In Australia, accreditation requirements call for the inclusion of sustainability in engineering education, but patchy implementation is done with some universities integrating sustainability across their curricula and others inserting it as a separate module (Arefin et al., 2021). In Europe, inter-disciplinary undergraduate programs in Sweden and the Netherlands focus on systems thinking and life-cycle analysis to prepare students to handle intricate issues of sustainability. Most of them, however, overlook the economic and social aspects of sustainability and focus on technical solutions In North America, sustainability is usually included under electives and not as a requirement. Although leading universities have initiated sustainability research centers and programs, undergraduate engineering education has yet to develop a consistent method of teaching for sustainability (Fenner et al., 2014).

Despite a few encouraging trends in sustainability education, significant limitations remain. Most programs continue to neglect the development of genuine interdisciplinary collaboration, with an uneven emphasis on technical sustainability aspects (Cisek and Jaglarz, 2021). Students of engineering seldom study social sciences, economics, or policy studies and thus have only limited understanding of the wider implications of sustainability (Yosie, 2014). Also, there is little industry interaction with minimal universities being strongly linked with industries and organizations involved in sustainable engineering (Crofton, 2000). This gap between the academia and the industry renders the students unable to handle problems in real life.

A further essential gap is the absence of standard measurement criteria (Kazimieras Staniškis and Katiliute, 2016). Although instruments such as LEED and Envision provide guidelines for sustainable design, there is no standard way of measuring sustainability competencies in the various fields of engineering. In the absence of specified learning outcomes, it is challenging to ascertain whether students are actually acquiring the knowledge and skills to carry out sustainable engineering practice effectively (Hadgraft and Kolmos, 2020).

While current sustainability initiatives offer valuable tools and learning experiences, their fragmented implementation fails to equip engineers with comprehensive sustainability competencies. This lack of standardized measurement criteria for sustainability proficiency remains a critical gap (Guerra, 2017). To address this, engineering curricula must transcend standalone sustainability courses and instead weave sustainability fundamentals systematically throughout all program elements. This gap persists despite ongoing efforts to modernize accreditation standards. For example, ABET has recently updated its criteria to explicitly require the integration of sustainability outcomes within engineering programs, signaling a broader shift within the discipline (University World News, 2023). To align with these evolving benchmarks, institutions must move beyond offering sustainability as a set of isolated electives and instead embed its principles holistically across the curriculum—ensuring both technical rigor and a measurable societal impact. There is a necessity to embark on more structured, interdisciplinary, and hands-on approaches to preparing engineers for tackling the realities of sustainable development.

4 A new vision: systemic change for sustainability education

Sustainability education requires a transformative shift in curricula, pedagogies, and institutional structures to cultivate eight key competencies, systems thinking, futures thinking, values thinking, strategic thinking, interpersonal skills, intrapersonal awareness, implementation, and integration, equipping learners to address complex global challenges and drive societal transformations toward the Sustainable Development Goals (Redman and Wiek, 2021). In order for engineering education to respond effectively to sustainability issues, there needs to be a change in its underlying strategy (Sigahi et al., 2022). The *ad hoc* approaches currently in place, whereby sustainability is taught as an optional subject instead of a key engineering principle, do not equip future engineers with the ability to develop economic, environmental, and social sustainability solutions (Beagon et al., 2022). We need a systemic change—one that reimagines education for sustainability, traversing disciplinary silos and theoretical discussion and toward holistic, experiential, and technology-supported learning patterns.

Systemic change for sustainability education requires a whole-institution approach, aligning curricula, pedagogies, and assessments to develop key competences, such as systems thinking, collaboration, and future-oriented problem-solving, in students, ensuring they are equipped to address complex global challenges and contribute to a sustainable future (Kioupi and Voulvoulis, 2022).

One of the most significant parts of this change is interdisciplinary working (Whittaker and Montgomery, 2022). Sustainability issues cannot be contained within conventional engineering disciplines; they need input from environmental science, social sciences, and economics (Zizka et al., 2021). Engineers need to know the effect of their designs on communities, economies, and ecosystems. In order to achieve this, engineering degree programs need to break down disciplinary silos and include courses or project collaborations that expose students to scholars of public policy, business scholars, and scholars of environmental studies (Beagon et al., 2022). Systems thinking will guarantee that engineers don't merely fix disconnected technical issues but also regard the wider implications of their projects. Universities need to promote interdisciplinarity between engineering and other fields by means of shared coursework, research studies, and case studies that introduce students to the complexity of sustainable development (Mares-Nasarre et al., 2023).

Apart from interdisciplinary education, project-based and experiential learning is also vital in acquiring real-world sustainability competencies (Redman and Wiek, 2021). The conventional lecture method of learning cannot capture the intricacies of applying sustainable solutions. Rather, students need to be involved in real-world projects, fieldwork, and interaction with industry partners to acquire practical skills (Sanchez-Carrillo et al., 2021). Design-build competitions, sustainability consulting projects, and cooperative education with green technology businesses provide students with the ability to connect theory and practice. Universities must actively collaborate in cooperation with municipalities, businesses, and non-profit organizations involved in sustainability efforts to allow students to assist in current projects in urban planning, renewable energy, and resource management (Hou et al., 2023). This revision will have graduates enter the workforce with practical experience, ready to implement sustainable engineering principles.

Despite increased attention to sustainability in higher education, there remains a disconnect between pedagogical approaches and the development of sustainability competences. A systemic shift is needed that emphasizes experiential, participatory, and real-world learning strategies, such as project-based learning and community service learning, to effectively cultivate the full spectrum of sustainability competences in future professionals (Lozano et al., 2017).

However, radical transformation in sustainability education will remain elusive unless there are policy and accreditation reforms. Accreditation bodies and governing boards like ABET, Engineers Australia, and European accreditation boards need to revise their standards to render sustainability a competency area instead of an elective topic (Sandanayake et al., 2022). The universities need to be encouraged to introduce sustainability into all areas of engineering, so that it becomes part of core subjects instead of a specialized topic. The assessment systems also need to be revised—conventional examination and coursework are not enough to evaluate an engineer's competency in implementing sustainability principles. Other evaluation frameworks, including portfolio evaluations, sustainability impact projects, and industry evaluations, need to be taken into consideration in order to make sure that students graduate with evidenced sustainability competencies (Gutierrez-Bucheli et al., 2022). Pedagogical principles that foster critical consciousness can drive systemic change in sustainability education by integrating racial equity and social justice, equipping students to engage with global challenges in diverse contexts (Potter et al., 2023).

Lastly, technology and digital instruments provide new avenues to support education for sustainability. Virtual reality (VR), artificial intelligence (AI), and digital twins have the potential to provide immersive learning experiences to students, enabling them to simulate sustainable designs, validate engineering solutions in virtual laboratories, and study long-term environmental effects (Hou et al., 2023). They allow students to test various measures of sustainability in city planning, water management, and energy systems without the limitations of real-world implementation constraints (Mares-Nasarre et al., 2023). Through the integration of sophisticated simulation software and AI-based sustainability analysis into studies, universities are able to provide students with state-of-the-art skills that are progressively sought after in the job market (Sandanayake et al., 2022).

For systemic change to be realized in sustainability education, it has to be a multilateral effort incorporating interdisciplinary learning, experiential learning, institutional transformation, as well as emerging technologies (Yue and Ji, 2020). It is through making sustainability a cornerstone of engineering education that engineers will be equipped with the necessary capacities to tackle the looming environmental and societal crises of the future.

5 The way forward

The imperative to restructure sustainability education in engineering is evident. Although efforts to date have placed sustainability themes in curricula, these remain fragmented and inadequate (Hadgraft and Kolmos, 2020). Tackling climate change, depletion of resources, and environmental degradation necessitates a paradigm shift—one that incorporates sustainability as an underlying principle, not an add-on subject (Sandanayake et al., 2022). Universities, policymakers, and industry stakeholders need to collaborate to bring this change about, making sure that engineers in the future are able to create sustainable solutions.

In order to highlight the most important challenges, current activities, and the required reforms, Table 1 below presents an overview of the shortcomings in sustainability education and the system changes that must be undertaken in order to bridge them:

In the future, universities need to adopt interdisciplinary teamwork, experiential learning, and technology to promote

TABLE 1 Challenges, current approaches, and proposed solutions for sustainability education in engineering.

Challenge	Current approaches	Proposed solutions
Traditional engineering paradigms	Focus on technical problem-solving with limited sustainability integration.	Shift to **systems thinking** that includes environmental, social, and economic factors (Beagon et al., 2022; Sigahi et al., 2022).
Lack of interdisciplinary integration	Sustainability is taught in isolated courses with little collaboration between disciplines.	Embed **interdisciplinary coursework** merging engineering with environmental science, economics, and policy studies (Gutierrez-Bucheli et al., 2022; Redman and Wiek, 2021).
Resistance to curricular change	Accreditation bodies provide vague sustainability requirements, leading to inconsistent implementation.	**Policy and accreditation reforms** to mandate sustainability as a core competency in all engineering programs (Theis et al., 2008).
Limited practical exposure	Sustainability is mostly taught through lectures and case studies rather than real-world applications.	Expand **experiential learning** through industry partnerships, internships, and field-based sustainability projects (Hadgraft and Kolmos, 2020).
Weak industry involvement	Limited collaboration between universities and companies working on sustainability projects.	Strengthen **university-industry partnerships** to provide students with hands-on experience in sustainable engineering (Nazzal et al., 2015).
Insufficient use of technology	Digital tools such as AI, VR, and digital twins are underutilized in sustainability education.	Leverage **emerging technologies** to simulate sustainability scenarios and enhance learning outcomes (Hou et al., 2023).

sustainability education. Accreditation agencies need to have clear and enforceable sustainability standards so that all engineering students will have a solid grounding in sustainability (Sandanayake et al., 2022). Industry needs to become more involved, providing hands-on learning experiences that enable students to work on actual sustainability problems.

Future studies should aim to establish standardized metrics of assessment for sustainability competencies and investigate the impact of technology-enabled sustainability education. It is only through systemic, concerted effort that we can make sure the next generation of engineers is equipped to build a more sustainable and resilient world.

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References

Arefin, A., Md. Nabi, N., Md. Sadeque, S., and Gudimetla, P. (2021). Incorporating sustainability in engineering curriculum: a study of the Australian universities. *Int. J. Sustain. High. Educ.* 22:576. doi: 10.1108/IJSHE-07-2020-0271

Beagon, Ú., Kövesi, K., Tabas, B., Nørgaard, B., Lehtinen, R., Bowe, B., et al. (2022). Preparing engineering students for the challenges of the SDGs: what competences are required? *Eur. J. Eng. Educ.* 48:1. doi: 10.1080/03043797.2022.2033955

Brown, S., Bornasal, F., Brooks, S. M., and Martin, J. P. (2014). Civil engineering faculty incorporation of sustainability in courses and relation to sustainability beliefs. *J. Prof. Issues Eng. Educ. Pract.* 141:2. doi: 10.1061/(ASCE)EI.1943-5541.0000225

Burke, R., Dancz, C., Ketchman, K., M. Bilec, M., H. Boyer, T., I. Davidson, C., et al. (2018). Faculty perspectives on sustainability integration in undergraduate civil and environmental engineering curriculum. *J. Prof. Issues Eng. Educ. Pract.* 144:3. doi: 10.1061/(ASCE)EI.1943-5541.0000373

Cisek, E., and Jaglarz, A. (2021). Architectural education in the current of deep ecology and sustainability. *Buildings* 11:358. doi: 10.3390/buildings11080358

Crofton, F. S. (2000). Educating for sustainability: opportunities in undergraduate engineering. *J. Clean. Prod.* 8:397. doi: 10.1016/S0959-6526(00)00043-3

Fenner, R., Cruickshank, H., and Ainger, C. (2014). Sustainability in civil engineering education: why, what, when, where and how. *Proc. ICE. Eng. Sustain.* 167:228. doi: 10.1680/ensu.14.00002

Guerra, A. (2017). Integration of sustainability in engineering education. *Int. J. Sustain. High. Educ.* 18:436. doi: 10.1108/IJSHE-02-2016-0022

Gutierrez-Bucheli, L., Kidman, G., and Reid, A. (2022). Sustainability in engineering education: A review of learning outcomes. *J. Clean. Prod.* 330:129734. doi: 10.1016/j.jclepro.2021.129734

Hadgraft, R., and Kolmos, A. (2020). Emerging learning environments in engineering education. *Australas. J. Educ. Technol.* 25, 1–14. doi: 10.1080/22054952.2020.1713522

Hou, H., Lai, J. H. K., and Wu, H. (2023). Project-based learning and pedagogies for virtual reality-aided green building education: case study on a university course. *Int. J. Sustain. High. Educ.* 24:1308. doi: 10.1108/IJSHE-06-2022-0197

Jørgensen, U., Valderrama, A., Mathiesen, B. V., and Remmen, A. (2013). *How is sustainability incorporated into the engineering curriculum?* The case of DTU and AAU.

Jung, Y., Park, K., and Ahn, J. (2019). Sustainability in higher education: perceptions of social responsibility among university students. *Soc. Sci.* 8:90. doi: 10.3390/socsci8030090

Kazimieras Staniškis, J., and Katiliute, E. (2016). Complex evaluation of sustainability in engineering education: case and analysis. *J. Clean. Prod.* 120:13. doi: 10.1016/j.jclepro.2015.09.086

Kevern, J. T. (2010). Green building and sustainable infrastructure: sustainability education for civil engineers. *J. Prof. Issues Eng. Educ. Pract.* 137:107. doi: 10.1061/(ASCE)EI.1943-5541.0000048

Kioupi, V. and Voulvoulis, N. (2022). The contribution of higher education to sustainability: the development and assessment of sustainability competences in a university case study. *Educ. Sci.* 12:406. doi: 10.3390/educsci12060406

Lozano, R., Merrill, M., Sammalisto, K., Ceulemans, K., and Lozano, F. (2017). Connecting competences and pedagogical approaches for sustainable development in higher education: a literature review and framework proposal. *Sustainability* 9:1889. doi: 10.3390/su9101889

Lu, M. (2014). Integrating sustainability into the introduction of environmental engineering. *J. Prof. Issues Eng. Educ. Pract.* 141. doi: 10.1061/(ASCE)EI.1943-5541.0000227

Mares-Nasarre, P., Martínez-Ibáñez, V., and Sanz-Benlloch, A. (2023). Analyzing sustainability awareness and professional ethics of civil engineering bachelor's degree students. *Sustainability* 15:6263. doi: 10.3390/su15076263

McWhirter, N., and Shealy, T. (2018). Pedagogy and evaluation of an envision case study module bridging sustainable engineering and behavioral science. *J. Prof. Issues Eng. Educ. Pract.* 144. doi: 10.1061/(ASCE)EI.1943-5541.0000384

Nazzal, D., Zabinski, J. W., Hugar, A., Reinhart, D. R., Karwowski, W., and Madani, K. (2015). Introduction of sustainability concepts into industrial engineering education: a modular approach. *AEE J.* 4. Available online at: https://www.researchgate.net/publication/283328384_Introduction_of_Sustainability_Concepts_into_Industrial_Engineering_Education_a_Modular_Approach#fullTextFileContent

Potter, R., Hiser, K., Evans, T., and Feldman, I. (Eds.). (2023). *Key competencies: Practical approaches to teaching sustainability. Sustainability Curriculum Consortium and Association for the Advancement of Sustainability in Higher Education.* Available online at: https://www.curriculumforsustainability.org (accessed April 16, 2024).

Quelhas, O. L. G., Lima, G. B. A., Ludolf, N. V.-E., Meiriño, M. J., Abreu, C. G. S., Anholon, R., et al. (2019). Engineering education and the development of competencies for sustainability. *Int. J. Sustain. High. Educ.* 20:614. doi: 10.1108/IJSHE-07-2018-0125

Redman, A., and Wiek, A. (2021). Competencies for advancing transformations towards sustainability. *Front. Educ.* 6:484. doi: 10.3389/feduc.2021.785163

Roure, B., Anand, C., Bisaillon, V., and Amor, B. (2018). Systematic curriculum integration of sustainable development using life cycle approaches The case of the Civil

Engineering Department at the Université de Sherbrooke. *Int. J. Sustain. High. Educ.* 19, 393–418. doi: 10.1108/IJSHE-07-2017-0111

Sanchez-Carrillo, J. C., Cadarso, M., and Gómez, M. Á. T. (2021). Embracing higher education leadership in sustainability: a systematic review. *J. Clean. Prod.* 298:126675. doi: 10.1016/j.jclepro.2021.126675

Sandanayake, M., Bouras, Y., and Vrcelj, Z. (2022). Environmental sustainability in infrastructure construction—a review study on australian higher education program offerings. *Infrastructures* 7:109. doi: 10.3390/infrastructures7090109

Shields, D., Verga, F., and Andrea Blengini, G. (2014). Incorporating sustainability in engineering education. *Int. J. Sustain. High. Educ.* 15, 390–403. doi: 10.1108/IJSHE-02-2013-0014

Sigahi, T. F. A. C., Rampasso, I. S., Anholon, R., and Sznelwar, L. I. (2022). Classical paradigms versus complexity thinking in engineering education: an essential discussion in the education for sustainable development. *Int. J. Sustain. High. Educ.* 24:179. doi: 10.1108/IJSHE-11-2021-0472

Theis, R., Watkins, P., and Beck, M. A. (2008). "Pathways to learning: orchestrating the role of sustainability in engineering education," in *2008 Annual Conference & Exposition*, p. 13–966.

Thürer, M., Tomašević, I., Stevenson, M., Qu, T., and Huisingh, D. (2018). A systematic review of the literature on integrating sustainability into engineering curricula. *J. Clean. Prod.* 181:608. doi: 10.1016/j.jclepro.2017.12.130

University World News. (2023). *Embedding HE sustainability in criteria for accrediting degrees*. Available online at: https://www.universityworldnews.com/post.php?story=20230916074130111 (accessed April 16, 2024).

Venugopal, P., and Kour, H. (2020). Integrating the circular economy into engineering programs in India: a study of students' familiarity with the concept. *Industry High. Educ.* 35:264. doi: 10.1177/0950422220967542

White, R. M., Möbius, K., King, B., Leask, K., Peres, S., Walker, J., et al. (2017). *A handbook for monitoring and evaluating education for sustainable development in higher education*. University of St Andrews. Available online at: https://www.qaa.ac.uk/membership/collaborative-enhancement-projects/education-for-sustainable-development/monitoring-and-evaluating-education-for-sustainable-development-in-higher-education (accessed April 16, 2024).

Whittaker, J. A., and Montgomery, B. L. (2022). Advancing a cultural change agenda in higher education: issues and values related to reimagining academic leadership. *Disc. Sustain.* 3. doi: 10.1007/s43621-022-00079-6

Yosie, T. F. (2014). Sustainable Innovation for Private and Public Sector Infrastructure: Next Generation Challenges for Engineering *Education.* ASCE Library. doi: 10.1061/9780784478745.088

Yue, X., and Ji, R. (2020). *Teacher Professional Competencies in Education for Sustainable Development*. In IntechOpen eBooks. London: IntechOpen. doi: 10.5772/intechopen.94991

Zizka, L., McGunagle, D., and J. Clark, P. (2021). Sustainability in science, technology, engineering and mathematics (STEM) programs: authentic engagement through a community-based approach. *J. Clean. Prod.* 279:123715. doi: 10.1016/j.jclepro.2020.123715