Embracing Biodiversity: A Perspective on Transforming Engineering Education for Sustainable Innovation

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Abstract

In a rapidly changing world marked by escalating environmental challenges, the imperative to integrate biodiversity knowledge into engineering education has never been more pressing. This perspective paper aims to explore the transformative potential of integrating biodiversity principles and practices into engineering curricula. Drawing upon interdisciplinary insights from environmental science, ecology, and engineering education, this paper advocates for a paradigm shift in engineering pedagogy to foster sustainable innovation. Through a lens of collaboration, creativity, and ethical stewardship, this paper explores how embracing biodiversity can empower engineers to address complex 21st-century challenges while nurturing a deeper connection between human ingenuity and the natural world. By illuminating the pathways to integrating biodiversity into engineering education, this paper aims to inspire educators, researchers, and practitioners to embark on a journey toward a more sustainable future.

Keywords: biodiversity, sustainability, innovation, transformative, ethical stewardship.

Introduction

Currently, the globe is at a critical juncture, dealing with unparalleled environmental difficulties arising from climate change, habitat degradation, pollution, and the extinction of species (Zhang et al., 2022). The intertwining of engineering and biodiversity holds profound implications for the future of our planet (Folke et al., 2021; McCormack et al., 2016). As stewards of innovation and agents of change, engineers are uniquely positioned to confront the multifaceted environmental challenges of the 21st century. Yet, traditional engineering education often overlooks the intricate web of life upon which our existence depends. Incorporating biodiversity into engineering education offers a significant chance to prepare upcoming engineers with the essential information, skills, and mindset needed to address the challenges of the 21st century, while also promoting a stronger bond with the natural world.

Traditional engineering curricula have predominantly focused on technical skills and knowledge, emphasizing areas such as mathematics, physics, and discipline-specific engineering principles (Chung, 2011). These programs are structured to produce engineers capable of designing and implementing solutions to technical problems, often with a primary focus on efficiency, cost-effectiveness, and functionality (Paz-Penagos & Pérez-Tristancho, 2022). While these skills are essential, the conventional approach often neglects the broader ecological context in which engineering solutions are applied. In recent years, however, there has been a growing recognition of the need to incorporate sustainability and environmental considerations into engineering education (Wilson, 2019). Despite this shift, the integration of biodiversity specifically remains limited. Initiatives such as the CDIO (Conceive-Design-Implement-Operate) framework have started to incorporate sustainability concepts (Isa et al., 2019), but they often do not explicitly address biodiversity.

One notable effort is the incorporation of sustainable engineering principles, which include aspects of biodiversity, in some curricula. For instance, courses on ecological engineering and green infrastructure are becoming more common, aiming to teach students how to design systems that support natural processes and enhance biodiversity (Dover, 2015; Herzog, 2016). Despite these advancements, the inclusion of comprehensive biodiversity education across all engineering disciplines is still sporadic and lacks a standardized approach. Nevertheless, several universities and institutions have begun to pioneer the integration of biodiversity into engineering education. For example, the University of British Columbia offers a program in Environmental Engineering that includes courses on ecosystem health and biodiversity conservation (Brunetti et al., 2003; Lee-Wardell et al., 2019; The University of British Columbia, 2024).

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Similarly, the Technical University of Denmark has developed courses that emphasize the importance of biodiversity in sustainable development projects (Technical University of Denmark, 2024).

In addition to these specific programs, emerging trends show a broader shift towards interdisciplinary approaches, combining engineering with ecology, biology, and environmental science. This holistic approach is reflected in projects like urban green spaces, where engineers work alongside ecologists to create habitats that support local wildlife while providing social and environmental benefits to urban populations (Ignatieva et al., 2011). By integrating biodiversity principles into engineering curricula, these programs are paving the way for a new generation of engineers who are not only technically proficient but also ecologically aware. This trend underscores the importance of continuing to evolve engineering education to meet the environmental challenges of the 21st century.

In this perspective paper, we advocate for a fundamental reimagining of engineering education—one that places biodiversity at its core. By embracing biodiversity as a guiding principle, we assert that engineering education can transcend its conventional boundaries, catalysing a paradigm shift toward sustainable innovation and ecological stewardship.

Overview of the Graduate Attributes and Professional Competencies

Based on the classifications provided by the International Engineering Alliance (IEA) in Table 1, engineering activities in educational programs encompass a variety of intricate, broadly defined, and clearly specified tasks. Table 2 also highlights that the Washington Accord, Sydney Accord, and Dublin Accord emphasize the knowledge and attitude profile among engineers through programs that provide a systematic, theory-based understanding of natural sciences relevant to the discipline, and awareness of relevant social sciences through WK1, SK1, and DK1.

Nevertheless, the classification largely prioritises the utilisation of natural resources without adequately considering biodiversity. Natural resources, referring to substances obtained from the environment for human utilisation, are separate from biodiversity, which comprises the diversity of life forms and ecosystems. The differentiation is crucial because biodiversity plays a fundamental role in providing necessary ecosystem services and promoting ecological resilience, which are becoming increasingly important for sustainable engineering solutions. The structure of the IEA may unintentionally neglect the significance of biodiversity in engineering education and professional skills, which could restrict the ability of graduates to effectively tackle urgent global environmental issues. By incorporating biodiversity directly into engineering curricula and competency frameworks, educational programmes can more effectively prepare future engineers to create comprehensive, sustainable solutions that harmonise technical advancement with environmental conservation.

Table 1. Range of engineering activities.

Attribute	Complex Activities	Broadly defined Activities	Well-defined Activities
Preamble	Complex activities mean (engineering) activities or projects that have some or all of the following characteristics:	Broadly defined activities mean (engineering) activities or projects that have some or all of the following characteristics:	Well-defined activities mean (engineering) activities or projects that have some or all of the following characteristics:
Range of resources	EA1: Involve the use of diverse resources including people, data and information, natural, financial and physical resources and appropriate technologies including analytical and/or design software	TA1: Involve a variety of resources including people, data and information, natural, financial and physical resources and appropriate technologies including analytical and/or design software	NA1: Involve a limited range of resources for example people, data and information, natural, financial and physical resources and/or appropriate technologies
Level of interactions	EA2: Require optimal resolution of interactions between wide-ranging and/or conflicting technical, non-technical, and engineering issues	TA2: Require the best possible resolution of occasional interactions between technical, non-technical, and engineering issues, of which few are conflicting	NA2: Require the best possible resolution of interactions between limited technical, non-technical, and engineering issues
Innovation	EA3: Involve creative use of engineering principles, innovative solutions for a conscious purpose, and research-based knowledge	TA3: Involve the use of new materials, techniques or processes in non-standard ways	NA3: Involve the use of existing materials techniques, or processes in modified or new ways
Consequences to society and the environment	EA4: Have significant consequences in a range of contexts, characterized by difficulty of prediction and mitigation.	TA4: Have reasonably predictable consequences that are most important locally, but may extend more widely	NA4: Have predictable consequences with relatively limited and localized impact.

Familiarity	EA5: Can extend beyond previous experiences by applying principles-based approaches.	TA5: Require a knowledge of normal operating procedures and processes	NA5: Require a knowledge of practical procedures and practices for widely applied operations and processes

Source: International Engineering Alliance. (2021)

Table 2. Knowledge and attitude profile

A Washington Accord program provides:	A Sydney Accord program provides:	A Dublin Accord program provides:
WK1: A systematic, theory-based understanding of the **natural sciences** applicable to the discipline and awareness of relevant social sciences	SK1: A systematic, theory-based understanding of the **natural sciences** applicable to the sub-discipline and awareness of relevant social sciences	DK1: A descriptive, formula-based understanding of the **natural sciences** applicable in a sub-discipline and awareness of directly relevant social sciences
WK2: Conceptually based mathematics, numerical analysis, data analysis, statistics and formal aspects of computer and information science to support detailed analysis and modelling applicable to the discipline	SK2: Conceptually based mathematics, numerical analysis, data analysis, statistics and formal aspects of computer and information science to support detailed consideration and use of models applicable to the sub-discipline	DK2: Procedural mathematics, numerical analysis, statistics applicable in a subdiscipline
WK3: A systematic, theory-based formulation of engineering fundamentals required in the engineering discipline	SK3: A systematic, theory-based formulation of engineering fundamentals required in an accepted sub-discipline	DK3: A coherent procedural formulation of engineering fundamentals required in an accepted sub-discipline
WK4: Engineering specialist knowledge that provides theoretical frameworks and bodies of knowledge for the accepted practice areas in the engineering discipline; much is at the forefront of the discipline.	SK4: Engineering specialist knowledge that provides theoretical frameworks and bodies of knowledge for an accepted sub-discipline	DK4: Engineering specialist knowledge that provides the body of knowledge for an accepted sub-discipline
WK5: Knowledge, including efficient resource use, environmental impacts, whole-life cost, re-use of resources, net zero carbon, and similar concepts, that supports engineering design and operations in a practice area	SK5: Knowledge, including efficient resource use, environmental impacts, whole-life cost, re-use of resources, net zero carbon, and similar concepts, that supports engineering design and operations using the technologies of a practice area	DK5: Knowledge that supports engineering design and operations based on the techniques and procedures of a practice area
WK6: Knowledge of engineering practice (technology) in the practice areas in the engineering discipline	SK6: Knowledge of engineering technologies applicable in the sub-discipline	DK6: Codified practical engineering knowledge in recognized practice area
WK7: Knowledge of the role of engineering in society and identified issues in engineering practice in the discipline, such as the professional responsibility of an engineer to public safety and sustainable development*	SK7 Knowledge of the role of technology in society and identified issues in applying engineering technology, such as public safety and sustainable development*	DK7: Knowledge of issues and approaches in engineering technician practice, such as public safety and sustainable development*
WK8: Engagement with selected knowledge in the current research literature of the discipline, awareness of the power of critical thinking and creative approaches to evaluate emerging issues	SK8: Engagement with the current technological literature of the discipline and awareness of the power of critical thinking	DK8: Engagement with the current technological literature of the practice area
WK9: Ethics, inclusive behaviour and conduct. Knowledge of professional ethics, responsibilities, and norms of engineering practice. Awareness of the need for diversity by reason of ethnicity, gender, age, physical ability etc. with mutual understanding and respect, and of inclusive attitudes	SK9: Ethics, inclusive behaviour and conduct. Knowledge of professional ethics, responsibilities, and norms of engineering practice. Awareness of the need for diversity by reason of ethnicity, gender, age, physical ability etc. with mutual understanding and respect, and of inclusive attitudes	DK9: Ethics, inclusive behaviour and conduct. Knowledge of professional ethics, responsibilities, and norms of engineering practice. Awareness of the need for diversity by reason of ethnicity, gender, age, physical ability etc. with mutual understanding and respect, and of inclusive attitudes

*Represented by the 17 UN Sustainable Development Goals (UN-SDG)

Source: International Engineering Alliance. (2021)

Embracing Biodiversity: A Catalyst for Transformation

Collaborative Learning Ecosystems

Breaking down disciplinary silos and fostering interdisciplinary collaboration are essential for integrating biodiversity into engineering education (Walcutt & Schatz, 2019), aligning with the principles of the Washington Accord, Sydney Accord, and Dublin Accord. These agreements, established by the International Engineering Alliance (IEA), emphasize the importance of equipping engineering graduates with holistic competencies that encompass natural sciences and sustainable practices (International Engineering Alliance, 2021).

Traditional educational structures often compartmentalize knowledge within disciplinary boundaries, hindering interdisciplinary collaboration (McNair et al., 2011). By cultivating collaborative learning ecosystems, educators can facilitate interactions between students, faculty, and professionals from diverse backgrounds, as advocated by the Sydney Accord and Dublin Accord (International Engineering Alliance., 2021). For instance, collaborative projects integrating engineers, biologists, and ecologists offer students opportunities to gain insights from multiple perspectives and apply interdisciplinary approaches to real-world challenges.

Integrating biodiversity into engineering education requires overcoming challenges such as curriculum design and resource allocation, issues recognized by the Washington Accord. This integration is crucial for addressing complex sustainability challenges posed by Industry 4.0, where digitalization and automation intersect with environmental concerns. Collaborative learning ecosystems provide platforms for engineers to collaborate with biologists, policymakers, and other stakeholders, co-creating innovative solutions that prioritize biodiversity conservation amidst technological advancements (Xiaolu, 2023). While interdisciplinary collaboration is essential, it necessitates navigating power dynamics and recognizing diverse knowledge systems. Effective collaboration, according to Wei et al. (2022), requires fostering a culture of openness and mutual learning, aligning with the IEA's emphasis on ethical stewardship and responsible innovation (IEA, n.d.). Furthermore, incentivizing interdisciplinary research within academia is vital, challenging existing reward structures that favour disciplinary excellence over collaborative efforts.

According to the International Engineering Alliance (IEA) classifications in Table 1, engineering activities in educational programmes should include a range of complex, widely defined, and explicitly characterised tasks. For example, courses like "Ecological Engineering in Urban Systems," which were created collaboratively by engineering and biodiversity specialists at University X, and "Biodiversity Conservation and Engineering Solutions," which are taught by interdisciplinary teams at University Y, demonstrate how biodiversity principles are incorporated into engineering curricula. These principles include studying insects for ecosystem health, using forensic analysis in conservation efforts, evaluating species richness, and understanding ecosystem dynamics and habitat management. These courses prioritise a structured, theory-driven comprehension of natural sciences that are applicable to engineering fields. They also promote an understanding of social sciences through WK1, SK1, and DK1, in accordance with the Washington Accord, Sydney Accord, and Dublin Accord. By incorporating the expertise of both engineering and biodiversity specialists in the development and implementation of courses, educational institutions enhance students' learning experiences and equip them to tackle current global challenges using inventive and environmentally friendly engineering solutions that consider the intricacies of biodiversity.

Cultivating Creativity through Biomimicry

Nature serves as a profound source of inspiration for innovation (Pathak, 2019), exemplified by biomimicry—an approach advocated by the Washington Accord and Sydney Accord. Biomimicry involves emulating nature's solutions to engineering challenges, promoting creativity and problem-solving skills among students (Bidwell & Smirnoff, 2022; International Engineering Alliance., 2021). By encouraging students to draw inspiration from the natural world, educators can unlock a treasure trove of sustainable design solutions.

Biomimicry taps into nature's vast reservoir of evolutionary solutions honed over millions of years of adaptation. By studying biological systems, students can gain insights into innovative design strategies that have already been tested and refined by nature (Vázquez-Villegas et al., 2024). This approach not only provides practical solutions to engineering challenges but also fosters a deeper appreciation for the complexity and resilience of natural ecosystems. While biomimicry offers valuable inspiration for engineering design, it's essential to recognize the limitations of directly translating biological principles into human-made technologies. Biological systems operate within specific ecological contexts and constraints, which may not always align with human needs or technological feasibility. Moreover, the ethical implications of mimicking nature should be carefully considered, particularly regarding issues of biodiversity conservation, animal welfare, and cultural appropriation.

Biomimicry inherently bridges the gap between biology and engineering, promoting cross-disciplinary learning and collaboration. By engaging with concepts from biology, ecology, and materials science, students develop a holistic understanding of how natural systems function and evolve. This interdisciplinary approach encourages students to think outside traditional disciplinary boundaries and draw upon diverse sources of knowledge to solve complex problems. While cross-disciplinary learning is valuable, it may also pose challenges related to curriculum integration and faculty expertise. Engineering programs often have rigid course requirements and limited flexibility for incorporating interdisciplinary content (Hitt et al., 2020). Moreover, faculty members may lack training or experience in biomimicry, making it challenging to teach effectively. Addressing these challenges requires institutional support for curriculum development, faculty training, and interdisciplinary collaboration. Educators play a crucial role in guiding students to critically evaluate the ecological and social consequences of biomimetic technologies, aligning with the IEA's commitment to ethical stewardship in engineering education (International Engineering Alliance., 2021).

Biomimicry fosters creativity and innovation by challenging students to think critically and creatively about engineering problems (Bidwell & Smirnoff, 2022). By encouraging students to observe, analyse, and emulate natural systems, educators can cultivate a mindset of curiosity, experimentation, and iterative design. Biomimetic solutions often require unconventional thinking and lateral problem-solving, providing students with valuable skills for addressing real-world challenges (Ersanlı & Ersanlı, 2023). While biomimicry can enhance students' problem-solving skills, it's important to balance creativity with practicality and feasibility. Not all biological solutions are suitable or scalable for human-made technologies, and students must learn to evaluate the viability and sustainability of biomimetic designs. Moreover, biomimicry should be complemented by a strong foundation in engineering principles and design methodologies to ensure that students develop robust and effective solutions.

According to Dicks (2023), biomimicry raises ethical questions about the appropriation of nature's designs and the potential impact on ecosystems and biodiversity. Educators must emphasize the importance of ethical stewardship and responsible innovation in biomimetic design. This includes considering the ecological and social consequences of biomimetic technologies, as well as engaging stakeholders in ethical discussions and decision-making processes. While biomimicry holds promise for sustainable innovation, it is essential to critically evaluate its ethical implications and potential unintended consequences. Biomimetic technologies must be developed and deployed in ways that prioritize environmental integrity, social equity, and cultural sensitivity (Fletcher et al., 2024). Educators play a crucial role in fostering ethical awareness and guiding students to consider the broader implications of their design choices.

In conclusion, biomimicry offers a powerful framework for cultivating creativity and problem-solving skills among engineering students. However, it's essential to approach biomimicry with a critical lens, considering its limitations, ethical implications, and the need for interdisciplinary collaboration. By integrating biomimicry into engineering education thoughtfully and responsibly, educators can inspire the next generation of innovators to harness the wisdom of nature in building a more sustainable and resilient future.

Ethical Stewardship and Social Responsibility

At the heart of biodiversity conservation lies a commitment to ethical stewardship and social responsibility. Engineering education must instil in students a deep sense of ethical awareness and a reverence for the interconnectedness of all life forms. By integrating ethical considerations into engineering curricula, educators can empower students to become responsible custodians of the planet.

Ethical stewardship involves recognizing the moral implications of engineering decisions and taking responsibility for their social and environmental consequences (Kelly, 2008; Tarnai-Lokhorst, 2019). Engineering students must develop a strong ethical foundation that guides their professional conduct and decision-making processes. This includes understanding the ethical principles of beneficence, non-maleficence, justice, and respect for autonomy, as well as considering the long-term impacts of their actions on ecosystems, communities, and future generations. While ethical awareness is essential, it can be challenging to instil in students, particularly within the context of traditional engineering education. Engineering curricula often prioritize technical skills and knowledge over ethical considerations, leading students to overlook or undervalue the ethical dimensions of their work. Moreover, ethical dilemmas in engineering are often complex and context-dependent, requiring students to navigate conflicting values and priorities (Gunckel & Tolbert, 2018; Lönngren et al., 2017). Addressing these challenges requires integrating ethics education into engineering curricula in a meaningful and engaging way, rather than treating it as an optional or peripheral component.

Ethical stewardship entails recognizing the intrinsic value of biodiversity and respecting the rights of non-human beings (Bieling et al., 2020). Engineering students should develop a deep appreciation for the beauty, diversity, and complexity of the natural world, as well as an understanding of humanity's interconnectedness with other species. This ecological perspective encourages students to consider the impacts of their actions on ecosystems and biodiversity, and to prioritize conservation and sustainability in their engineering practices. While promoting reverence for nature is commendable, it can sometimes perpetuate anthropocentric attitudes that prioritize human interests over the intrinsic value of non-human beings and ecosystems. Engineering education must challenge students to critically examine their anthropocentric biases and develop a more inclusive and ecocentric worldview that recognizes the inherent worth of all life forms. Moreover, fostering reverence for nature should not justify paternalistic or conservationist approaches that prioritize preserving nature for human use and enjoyment, rather than respecting nature's autonomy and integrity.

Social responsibility extends beyond environmental conservation to encompass considerations of equity, justice, and human well-being (Ibrahim et al., 2021, 2023; Žižek et al., 2021). Engineering students must recognize their role as agents of social change and advocate for solutions that promote social equity, diversity, and inclusion (Rodriguez et al., 2021). This includes addressing environmental injustices, supporting marginalized communities, and engaging stakeholders in decision-making processes to ensure that engineering solutions meet the needs of all members of society. While social responsibility is integral to ethical engineering practice, it can sometimes be overshadowed by a narrow focus on technical expertise and economic efficiency. Engineering education must broaden its scope to include social and cultural dimensions, empowering students to critically examine the societal impacts of their work and advocate for socially just and equitable solutions. Moreover, addressing social responsibility requires confronting systemic inequalities and power structures within engineering institutions and industries, which may be resistant to change.

The ethical stewardship and social responsibility are essential principles that should be integrated into engineering education to promote biodiversity conservation and sustainability. However, realizing these principles requires overcoming challenges related to curriculum design, institutional culture, and societal values. By critically examining these challenges and fostering a culture of ethical awareness and social responsibility, engineering educators can empower students to become responsible custodians of the planet and advocates for a more just and sustainable future.

Catalysing Transformative Innovation

The integration of biodiversity knowledge into engineering education has the potential to catalyse transformative innovation across a range of sectors (Zambrano-Gutiérrez & Puppim de Oliveira, 2022). From sustainable infrastructure development to ecological restoration projects, engineers equipped with a deep understanding of biodiversity can pioneer novel solutions that harmonize human needs with the natural world.

Biodiversity is a source of inspiration for innovative engineering solutions (Broeckhoven & du Plessis, 2022; Topaz, 2016). By understanding and emulating nature's designs and processes, engineers can develop novel technologies and approaches that are more sustainable, resilient, and biodiverse-friendly (Bianciardi & Cascini, 2023). For example, biomimetic design principles can lead to the development of materials that are stronger, lighter, and more energy-efficient, drawing inspiration from structures found in nature such as spider silk or lotus leaves. While biomimicry holds promise for innovation, it is important to recognize that not all biomimetic solutions are feasible or practical in human-made contexts. Nature operates within specific ecological constraints and trade-offs that may not translate directly to engineering applications. Moreover, biomimetic technologies must be rigorously tested for safety, reliability, and scalability before being implemented at scale. Blindly mimicking nature without considering the broader social, economic, and ethical implications can lead to unintended consequences and reinforce anthropocentric biases.

Integrating biodiversity into engineering education can promote sustainable development by fostering a holistic understanding of ecological systems and their interconnectedness with human societies. Engineers equipped with biodiversity knowledge can design infrastructure and technologies that minimize environmental impact, conserve biodiversity, and enhance ecosystem services (White et al., 2021). For example, green infrastructure projects such as green roofs, rain gardens, and permeable pavements can mitigate urban runoff, reduce flooding, and improve water quality while providing habitat for wildlife. While promoting sustainable development is a laudable goal, it requires addressing systemic barriers and incentives that prioritize short-term economic gains over long-term environmental and social sustainability. Engineering education must challenge prevailing paradigms of growth and consumption and promote alternative models of development that prioritize equity, resilience, and well-being. Moreover, sustainable solutions must be context-specific and culturally appropriate, taking into account the diverse needs and aspirations of different communities and stakeholders.

Biodiversity knowledge can inform ecological restoration projects aimed at rehabilitating degraded ecosystems and conserving endangered species (Haq et al., 2023). Engineers can play a crucial role in designing and implementing restoration strategies that enhance habitat connectivity, restore hydrological processes, and reintroduce native species. By restoring ecosystem health and function, these projects can provide multiple benefits, including carbon sequestration, flood mitigation, and recreation opportunities (Di Sacco et al., 2021). While ecological restoration is essential for biodiversity conservation, it must be approached with caution and humility, recognizing the inherent complexity and uncertainty of ecological systems. Restoration projects can have unintended consequences (Taguchi et al., 2020), such as introducing invasive species or disrupting existing ecological processes. Moreover, restoration efforts must engage local communities and indigenous peoples as partners and stewards of the land, respecting their traditional knowledge and rights. Failure to do so can perpetuate colonial legacies of exploitation and marginalization.

Catalysing transformative innovation through the integration of biodiversity knowledge into engineering education holds immense promise for addressing pressing environmental challenges and promoting sustainable development. However, realizing this potential requires addressing critical gaps and challenges related to feasibility, scalability, social equity, and cultural sensitivity. By critically examining these issues and fostering a culture of interdisciplinary collaboration and ethical stewardship, engineering educators can empower students to become agents of positive change in building a more sustainable and biodiverse-friendly future.

Integrating Biodiversity Knowledge Across Engineering Disciplines

Integrating biodiversity knowledge across engineering disciplines can significantly enhance students' ability to address environmental challenges through interdisciplinary approaches. In civil engineering, incorporating sustainable urban planning and ecological engineering principles can help students understand the importance of green infrastructure and urban green spaces. For instance, courses could include projects where students design city parks using native plant species to support local wildlife or restore degraded wetland areas to improve water quality and provide habitats (Fang et al., 2023). Moreover, training in environmental impact assessments (EIAs) with a strong focus on biodiversity would enable students to assess construction projects' potential impacts on local ecosystems and develop effective mitigation strategies.

Chemical engineering can integrate biodiversity knowledge through green chemistry and sustainable bioprocessing, emphasizing processes that minimize environmental harm (Jiménez-González & Constable, 2011). Environmental biotechnology courses could teach students about using biological processes for environmental remediation, such as designing bioreactors to degrade pollutants in industrial wastewater. Moreover, focusing on sustainable resource management would highlight the importance of conserving biodiversity in the sourcing and processing of raw materials, encouraging students to analyze the life cycle of chemical products for biodiversity impacts.

Electrical engineering can contribute by emphasizing renewable energy systems' role in conserving biodiversity by reducing habitat destruction associated with fossil fuel extraction (Nazir et al., 2020). Courses could explore smart grid technologies that mitigate electrical infrastructure's impact on wildlife, such as developing bird-safe designs for power lines and substations (Hastik et al., 2015). Additionally, teaching sensor technology's applications in biodiversity conservation, like monitoring wildlife populations, can prepare students to support environmental protection efforts.

Mechanical engineering can integrate biodiversity knowledge by teaching eco-design principles and lifecycle assessments that consider biodiversity impacts (Fernandes et al., 2020). Sustainable manufacturing methods that reduce emissions, waste, and energy consumption can be incorporated into the curriculum. For example, students could develop manufacturing processes for automotive parts using recycled materials to minimize waste. Furthermore, biomechanics and bioinspired design courses can inspire students to create engineering solutions based on biological systems, such as designing robotic systems that mimic animal movements to navigate complex environments (Manoonpong et al., 2021).

Implementing these changes requires interdisciplinary courses and projects, collaborations with biology departments, field studies, and real-world applications to give students hands-on experience. Guest lectures and workshops by biodiversity and conservation experts can further enhance the curriculum. By integrating biodiversity knowledge into civil, chemical, electrical, and mechanical engineering curricula, educational institutions can prepare engineers capable of creating sustainable solutions that protect and enhance the natural environment.

In the context of engineering education, the graduate attribute profiles for different types of engineering graduates—Engineer, Engineering Technology graduate, and Engineering Technician—highlight distinct competencies related to natural science (in Table 1). Engineer graduates are equipped to apply a comprehensive understanding of mathematics, natural science, computing, and engineering fundamentals, leveraging specialized knowledge to tackle intricate engineering challenges. Their training emphasizes the integration of multidisciplinary principles, including sustainable development considerations, aligning with accreditation standards such as those set by ABET (2021). Conversely, Engineering Technology graduates focus on applying foundational knowledge of mathematics, natural science, and engineering fundamentals to execute defined engineering procedures and employ appropriate analytical tools suited to their field of specialization. This aligns with educational frameworks which include Framework for P-12 Engineering Learning which emphasizing applied skills and practical problem-solving capabilities, as articulated by American Society for Engineering Education (2020). Engineering Technician graduates, on the other hand, demonstrate proficiency in applying mathematical and scientific principles alongside engineering fundamentals to execute specific technical procedures and practices. Their training underscores the application of codified methods within their specialized field, reflecting a strong emphasis on practical execution and technical expertise (National Science Board, 2019). However, in the context of problem analysis, it is evident that engineering technologists and technicians may lack the depth of natural science elements compared to engineering graduates.

Therefore, this suggests that engineering graduates have a more extensive and profound theoretical knowledge in natural science, which allows them to effectively analyse and create intricate problems. Their education equips them to tackle complex engineering difficulties that demand a sophisticated level of conceptualization and the integration of several scientific principles. Conversely, engineering technologists and technicians prioritize the hands-on implementation of established methods and protocols. Although they excel in implementing and optimizing solutions in their field, they may lack the necessary skills to innovate or create new approaches that require extensive scientific knowledge. This distinction emphasizes the specific responsibilities that each type of engineering professional has in the industry, emphasizing the significance of having a diverse workforce that utilizes the individual strengths of engineers, technologists, and technicians to create comprehensive and efficient engineering solutions.

Based on the classifications provided by the International Engineering Alliance (IEA) in Table 3, engineering activities within educational programs involve a variety of intricate, broadly outlined, and clearly defined jobs. Nevertheless, the classification mainly prioritizes the utilization of natural resources while neglecting to adequately account for biodiversity. Natural resources refer to elements obtained from the environment for human utilization, whereas biodiversity comprises the diversity of life forms and ecosystems. The differentiation is crucial because biodiversity plays a crucial role in providing critical ecosystem services and bolstering ecological resilience, both of which are becoming increasingly important for sustainable engineering solutions. The structure of the IEA may unintentionally disregard the significance of biodiversity in engineering education and professional skills, which could potentially restrict the ability of graduates to effectively tackle urgent global environmental issues. Integrating biodiversity into engineering curriculum and competence frameworks can enhance educational programs by equipping future engineers with the skills to create sustainable solutions that combine technology innovation with environmental stewardship.

Conclusion and recommendations

To summarize, this perspective paper emphasizes the immediate necessity for a fundamental change in engineering education that incorporates biodiversity concepts. While sustainability elements are already implemented in engineering education, biodiversity education remains insufficiently addressed. Specifically, this change involves revising curricula to include biodiversity as a core component and integrating it into existing courses. The teaching methods illustrated in Figure 1, such as problem-based learning, field-based learning, project-based learning, and case studies, represent innovative approaches for integrating biodiversity into engineering education.

Table 3. Graduate attribute profile related to natural science.

Differentiating characteristics	Engineer graduate	Engineering technology graduate	Engineering technician graduate
Engineering Knowledge	Apply knowledge of mathematics, **natural science**, computing and engineering fundamentals, and an engineering specialization as specified in WK1 to WK4 respectively to develop solutions to complex engineering problems.	Apply knowledge of mathematics, **natural science**, computing and engineering fundamentals and an engineering specialization as specified in SK1 to SK4 respectively to defined and applied engineering procedures processes, systems or methodologies.	Apply knowledge of mathematics, **natural science**, engineering fundamentals and an engineering specialization as specified in DK1 to DK4 respectively to wide practical procedures and practices.
Problem analysis	Identify, formulate, research literature, and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, **natural sciences** and engineering sciences with holistic considerations for sustainable development*	Identify, formulate, research literature and analyze broadly defined engineering problems reaching substantiated conclusions using analytical tools appropriate to the discipline or area of specialisation	Identify and analyze well-defined engineering problems reaching substantiated conclusions using codified methods of analysis specific to their field of activity.

Source: International Engineering Alliance. (2021)

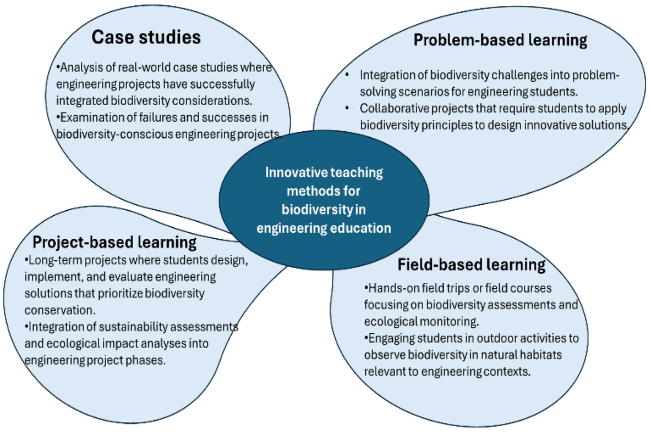

Figure 1. Innovative teaching methods for biodiversity in engineering education

We have seen that including biodiversity into engineering education can empower future engineers to address the unprecedented environmental challenges that our world is presently confronting. By embracing biodiversity, engineers will be able to take the lead in making innovative advancements. They will design transformative inventions that meet human needs while also showing respect and harmony with the natural environment. The significance of collaborative learning environments in breaking down disciplinary barriers and fostering interdisciplinary collaboration has been a central focus of our discussion. Engineers may effectively tackle intricate problems by establishing collaborative environments that bring together engineering students with peers from environmental sciences (e.g. entomology, conservation biology, ecology, wildlife, herpetofauna, etc.) and other disciplines. This allows engineers to benefit from other perspectives and collectively develop groundbreaking solutions.

Furthermore, biomimicry is acknowledged as a powerful framework for cultivating creativity and problem-solving skills in engineering students. In order to successfully include biomimicry into engineering education, it is necessary to incorporate dedicated courses that focus on the principles of biomimicry, project-based learning modules that entail practical applications in real-world scenarios and establish collaborations with industries and organizations that actively engage in biomimicry practices. Engineers can develop sustainable technology by replicating natural processes and deriving inspiration from the designs seen in nature. This technique enhances both resilience and biodiversity conservation.

Engineering education should include ethical stewardship and social responsibility as fundamental principles. Through the incorporation of ethics courses that specifically address sustainability and social fairness, educators can cultivate conscientious engineers who prioritize these principles in their professional endeavours. Incorporating biodiversity knowledge into engineering education has the capacity to inspire revolutionary innovation for a future that is both environmentally sustainable and conducive to biodiversity. By embracing this shift and encouraging collaboration, ingenuity, and principled guidance, we can prepare the next generation of engineers to serve as agents for constructive change in safeguarding the future of our planet. This requires not only recognizing the significance of biodiversity but also actively reorganizing educational structures to properly support and implement these modifications.

References

ABET. (2021). Criteria for accrediting Engineering Technology Programs. In *ABET*. https://www.abet.org/wp-content/uploads/2021/01/T001-21-22-ETAC-Criteria-1.pdf

American Society for Engineering Education. (2020). *Framework for P-12 Engineering Learning: A Defined and Cohesive Educational Foundation for P-12 Engineering* (G. Strimel, T. Huffman, M. Grubbs, J. Gurganus, A. Sabarre, & S. Bartholomew (eds.)). American Society for Engineering Education. https://doi.org/10.18260/1-100-1153-1

Bianciardi, A., & Cascini, G. (2023). How would nature design and implement nature-based solutions? *Nature-Based Solutions*, *3*, 100047.

Bidwell, D., & Smirnoff, D. (2022). Nature as Mentor: Catalyzing First-Year Liberal Arts and Sciences Undergraduate Transition through a Biomimicry First-Year Seminar. *International Journal of Teaching and Learning in Higher Education*, *34*(1), 124–143.

Bieling, C., Eser, U., & Plieninger, T. (2020). Towards a better understanding of values in sustainability transformations: ethical perspectives on landscape stewardship. *Ecosystems and People*, *16*(1), 188–196.

Broeckhoven, C., & du Plessis, A. (2022). Escaping the labyrinth of bioinspiration: biodiversity as key to successful product innovation. *Advanced Functional Materials*, *32*(18), 2110235.

Brunetti, A. J., Petrell, R. J., & Sawada, B. (2003). SEEDing sustainability: Team project-based learning enhances awareness of sustainability at the University of British Columbia, Canada. *International Journal of Sustainability in Higher Education*, *4*(3), 210–217.

Chung, C. (2011). Changing engineering curriculum in the globalizing world. *New Horizons in Education*, *59*(3), 59–70.

Di Sacco, A., Hardwick, K. A., Blakesley, D., Brancalion, P. H. S., Breman, E., Cecilio Rebola, L., Chomba, S., Dixon, K., Elliott, S., & Ruyonga, G. (2021). Ten golden rules for reforestation to optimize carbon sequestration, biodiversity recovery and livelihood benefits. *Global Change Biology*, *27*(7), 1328–1348.

Dicks, H. (2023). *The biomimicry revolution: Learning from nature how to inhabit the earth*. Columbia University Press.

Dover, J. W. (2015). *Green infrastructure: incorporating plants and enhancing biodiversity in buildings and urban environments*. Routledge.

Ersanlı, E. T., & Ersanlı, C. C. (2023). Biomimicry: Journey to the Future with the Power of Nature. *International Scientific and Vocational Studies Journal*, *7*(2), 149–160.

Fang, X., Li, J., & Ma, Q. (2023). Integrating green infrastructure, ecosystem services and nature-based solutions for urban sustainability: A comprehensive literature review. *Sustainable Cities and Society*, 104843.

Fernandes, A., Facca, C. A., Alves, J. L., Rangel, B., Leite, R., Neto, B., & Barbosa, A. M. T. B. (2020). Sustainability as a theme of interdisciplinarity between design and engineering courses. *2020 IEEE Global Engineering Education Conference (EDUCON)*, 1370–1376.

Fletcher, C., Ripple, W. J., Newsome, T., Barnard, P., Beamer, K., Behl, A., Bowen, J., Cooney, M., Crist, E., & Field, C. (2024). Earth at risk: An urgent call to end the age of destruction and forge a just and sustainable future. *PNAS Nexus*, *3*(4), pgae106.

Folke, C., Polasky, S., Rockström, J., Galaz, V., Westley, F., Lamont, M., Scheffer, M., Österblom, H., Carpenter, S. R., & Chapin, F. S. (2021). Our future in the Anthropocene biosphere. *Ambio*, *50*, 834–869.

Gunckel, K. L., & Tolbert, S. (2018). The imperative to move toward a dimension of care in engineering education. *Journal of Research in Science Teaching*, *55*(7), 938–961.

Haq, S. M., Pieroni, A., Bussmann, R. W., Abd-ElGawad, A. M., & El-Ansary, H. O. (2023). Integrating traditional ecological knowledge into habitat restoration: implications for meeting forest restoration challenges. *Journal of Ethnobiology and Ethnomedicine*, *19*(1), 33.

Hastik, R., Basso, S., Geitner, C., Haida, C., Poljanec, A., Portaccio, A., Vrščaj, B., & Walzer, C. (2015). Renewable energies and ecosystem service impacts. *Renewable and Sustainable Energy Reviews*, *48*, 608–623.

Herzog, C. P. (2016). A multifunctional green infrastructure design to protect and improve native biodiversity in Rio de Janeiro. *Landscape and Ecological Engineering*, *12*(1), 141–150.

Hitt, S. J., Holles, C. E. P., & Lefton, T. (2020). Integrating Ethics in Engineering Education through Multidisciplinary Synthesis, Collaboration, and Reflective Portfolios. *Advances in Engineering Education*.

Ibrahim, M. S. N., Adam Assim, M. I. S., Johari, S., Wan Mohammad, S. K., & Hassan, S. (2021). Influence of knowledge, attitude, and experience towards biodiversity conservation: Case study of Bako National Park, Sarawak, Malaysia. *The Malaysian Forester*, *84*(2), 255–270.

Ibrahim, M. S. N., Johari, S., Adam Assim, M. I. S., Mohammad Afandi, S. H., Khan, W. R., & Hassan, S. (2023). Community well-being dimensions in Gunung Mulu National Park, Sarawak, Malaysian Borneo. *Humanities and Social Sciences Communications*, *10*(1), 1–15. https://doi.org/10.1057/s41599-023-01737-4

Ignatieva, M., Stewart, G. H., & Meurk, C. (2011). Planning and design of ecological networks in urban areas. *Landscape and Ecological Engineering*, *7*, 17–25.

International Engineering Alliance. (2021). International Engineering Alliance Graduate Attributes & Professional Competencies. In *The International Engineering Alliance* (Vol. 4, Issue 21 June 2021).

Isa, C. M. M., Mustaffa, N. K., Preece, C. N., & Lee, W.-K. (2019). Enhancing conceive-design-implement-operate and design thinking (CDIO-DT) skills through problem-based learning innovation projects. *2019 IEEE 11th International Conference on Engineering Education (ICEED)*, 41–46.

Jiménez-González, C., & Constable, D. J. C. (2011). *Green chemistry and engineering: a practical design approach*. John Wiley & Sons.

Kelly, B. (2008). Sustainability in engineering education and ethics. *Connexions*.

Lee-Wardell, S., Lin, M., & Sha, C. J. (2019). *The Vital Importance of Biodiversity at UBC Cascading Fountain*.

Lönngren, J., Ingerman, Å., & Svanström, M. (2017). Avoid, control, succumb, or balance: Engineering students' approaches to a wicked sustainability problem. *Research in Science Education*, *47*, 805–831.

Manoonpong, P., Patanè, L., Xiong, X., Brodoline, I., Dupeyroux, J., Viollet, S., Arena, P., & Serres, J. R. (2021). Insect-inspired robots: bridging biological and artificial systems. *Sensors*, *21*(22), 7609.

McCormack, C. G., Born, W., Irvine, P. J., Achterberg, E. P., Amano, T., Ardron, J., Foster, P. N., Gattuso, J.-P., Hawkins, S. J., & Hendy, E. (2016). Key impacts of climate engineering on biodiversity and ecosystems, with priorities for future research. *Journal of Integrative Environmental Sciences*, *13*(2–4), 103–128.

McNair, L. D., Newswander, C., Boden, D., & Borrego, M. (2011). Student and faculty interdisciplinary identities in self-managed teams. *Journal of Engineering Education*, *100*(2), 374–396.

National Science Board. (2019). *The skilled technical workforce: Crafting America's science & engineering enterprise*. National Science Board. https://www.nsf.gov/nsb/publications/2019/nsb201923.pdf

Nazir, M. S., Bilal, M., Sohail, H. M., Liu, B., Chen, W., & Iqbal, H. M. N. (2020). Impacts of renewable energy atlas: Reaping the benefits of renewables and biodiversity threats. *International Journal of Hydrogen Energy*, *45*(41), 22113–22124.

Pathak, S. (2019). Biomimicry:(innovation inspired by nature). *International Journal of New Technology and Research*, *5*(6), 34–38.

Paz-Penagos, H., & Pérez-Tristancho, C. A. (2022). Engineering design: complexity in its teaching. *Dyna*, *89*(SPE222), 28–38.

Rodriguez, A. J., Ciftci, A., Howell, K., Kokini, K., Wright, B., & Nikalje, A. (2021). Promoting equity, diversity and social justice through faculty-led transformative projects. *Innovative Higher Education*, 1–22.

Taguchi, V. J., Weiss, P. T., Gulliver, J. S., Klein, M. R., Hozalski, R. M., Baker, L. A., Finlay, J. C., Keeler, B. L., & Nieber, J. L. (2020). It is not easy being green: Recognizing unintended consequences of green stormwater infrastructure. *Water*, *12*(2), 522.

Tarnai-Lokhorst, K. V. (2019). Instilling engineering students with social responsibility: Technological stewardship. *Proceedings of the Canadian Engineering Education Association (CEEA)*.

Technical University of Denmark. (2024). *Department of Environmental and Resource Engineering: Projects*. Technical University of Denmark. https://orbit.dtu.dk/en/organisations/department-of-environmental-and-resource-engineering

The University of British Columbia. (2024). *UBC Environmental Engineering Program*. The University of British Columbia. https://environmental.engineering.ubc.ca/

Topaz, M. (2016). Bioinspiration education at zoological institutions: an optimistic approach for innovation leading to biodiversity conservation. *International Zoo Yearbook*, *50*(1), 112–124.

Vázquez-Villegas, P., Geny Molina-Solis, E., Alberto Mejía-Manzano, L., Romo-Molina, J., & Membrillo-Hernández, J. (2024). Creating Sustainable Competencies in Engineering Through Biomimetics Courses. *International Journal of Engineering Pedagogy*, *14*(3).

Walcutt, J. J., & Schatz, S. (2019). Modernizing Learning: Building the Future Learning Ecosystem. *Advanced Distributed Learning Initiative*.

White, T. B., Viana, L. R., Campbell, G., Elverum, C., & Bennun, L. A. (2021). Using technology to improve the management of development impacts on biodiversity. *Business Strategy and the Environment*, *30*(8), 3502–3516.

Wilson, D. (2019). Exploring the intersection between engineering and sustainability education. *Sustainability*, *11*(11), 3134.

Xiaolu, L. (2023). Beyond boundaries: interdisciplinary perspectives on global challenges. *International Journal of*

Research and Review Techniques, *2*(2), 28–34.

Zambrano-Gutiérrez, J. C., & Puppim de Oliveira, J. A. (2022). The dynamics of sources of knowledge on the nature of innovation in the public sector: Understanding incremental and transformative innovations in local governments. *Journal of Public Administration Research and Theory*, *32*(4), 656–670.

Zhang, L., Xu, M., Chen, H., Li, Y., & Chen, S. (2022). Globalization, green economy and environmental challenges: state of the art review for practical implications. *Frontiers in Environmental Science*, *10*, 870271.

Žižek, S. Š., Mulej, M., & Potočnik, A. (2021). The sustainable socially responsible society: Well-being society 6.0. *Sustainability*, *13*(16), 9186.