

An AI-Assisted Systematic Review of Biology Learning Strategies for Sustainability

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Abstract

This study aims to uncover key strategies in biology learning that support sustainability through a Scopus AI-assisted literature review. Using a qualitative review approach combined with clustering and concept mapping techniques, 68 Scopus-indexed journal articles published between 2015 and 2025 were analyzed. Searches employed both natural language and Boolean keyword queries: ("biology" OR "life science") AND ("education" OR "learning") AND ("sustainability" OR "environmental"). Conceptual synthesis revealed three interrelated domains, Environmental Awareness, Student-centered Pedagogies, and Sustainability Education, each encompassing strategies such as experiential and problem-based learning, SDG-integrated modules, biomimicry-based innovation, and community engagement. These findings indicate that biology learning for sustainability extends beyond content mastery toward transformative pedagogy and ecological ethics, positioning biology as a platform for cultivating ecological citizenship. However, the study is limited by its reliance on Scopus AI metadata and abstracts, which may not fully capture methodological nuances and contextual depth of the original studies.

Keywords: Biology Education; Sustainability; Scopus AI; Clustering; Concept Mapping; Ecological Citizenship

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INTRODUCTION

In the face of escalating environmental crises, including biodiversity loss, climate change, and pollution, education has become an essential driver for sustainability transformation. Biology, as the science of life, occupies a central position in this global agenda by fostering ecological literacy, systems thinking, and ethical awareness toward living organisms and ecosystems (Chu & Karr, 2017; Husamah, Rahardjanto, Permana, & Lestari, 2025). Yet, despite its potential, the way biology is traditionally taught often fails to cultivate sustainability-oriented mindsets. Lessons tend to emphasize factual knowledge over inquiry, competition over collaboration, and laboratory mastery over environmental stewardship (Buerkle et al., 2023; Holman & Švejdárová, 2023; Kashdan & Rottenberg, 2010). Consequently, there is an urgent need to reimagine how students should learn biology to actively support sustainability in both theory and practice.

The integration of sustainability within biology education requires pedagogical frameworks that connect scientific understanding with values, attitudes, and actions. Recent literature increasingly highlights approaches such as Education for Sustainable Development (ESD), Science–Environment–Technology–Society (SETS) models, and eco-pedagogical frameworks as effective vehicles for cultivating sustainability competencies. These include critical thinking, problem-solving, ethical reasoning, and civic engagement—skills that enable learners to navigate complex socio-ecological challenges (Leal Filho et al., 2025; Li et al., 2025; Portus et al., 2024). However, there remains a gap between theoretical frameworks and classroom practice, particularly in translating sustainability principles into actionable learning experiences. To bridge this gap, educators and researchers must draw on empirical evidence and conceptual insights from current scientific discourse.

Although bibliometric and systematic reviews on sustainability education have proliferated, few have focused specifically on how biology learning supports sustainability, and even fewer have utilized artificial intelligence to reveal conceptual linkages and thematic trends. Traditional reviews often rely on manual coding, which is time-consuming, subjective, and limited in scope. This limitation underscores the need for innovative synthesis methods that can process large-scale scholarly metadata efficiently while maintaining conceptual depth.



Leveraging Scopus AI, this study systematically uncovers key strategies emerging from global scholarly discussions on how students should learn biology to support sustainability. Through text-mining of recent abstracts and synthesis of a concept map, several interrelated dimensions emerge—namely experiential learning, inquiry-based approaches, local wisdom integration, interdisciplinary collaboration, and digital innovation (Husamah et al., 2022; Husamah, Permana, & Rahardjanto, 2025; Husamah, Rahardjanto, & Permana, 2025; Husamah, Rahardjanto, Permana, Lestari, et al., 2025). These elements reflect a paradigm shift from content-driven instruction toward transformative, participatory, and future-oriented biology education. The findings aim to provide a strategic foundation for educators and curriculum designers seeking to realign biology learning with the goals of sustainability, echoing UNESCO's call for education that empowers learners to make responsible decisions for environmental integrity, social justice, and economic viability.

The novelty of this study lies in the use of Scopus AI as an AI-assisted platform that integrates natural language search, clustering, and concept mapping to identify conceptual relationships and emerging pedagogical trends from Scopus-indexed publications between 2015 and 2025. Compared to traditional reviews, Scopus AI offers significant advantages—speed, transparency, and visualization—enabling researchers to analyze thematic structures and knowledge gaps efficiently. However, this method also has limitations due to its reliance on abstracts and metadata rather than full-text analyses, which may overlook contextual and methodological nuances. Despite these constraints, Scopus AI provides a scalable, replicable, and insightful pathway for synthesizing the global discourse on sustainability-oriented biology education.

RESEARCH METHOD

This study employed a qualitative review approach to synthesize strategies in biology learning that support sustainability using secondary data from Scopus AI, an AI-integrated platform for retrieving and summarizing Scopus-indexed literature. Searches were conducted from September–October 2025 using both natural language (“How can students learn biology to support sustainability?”) and Boolean keyword queries covering 2015–2025 publications. Only peer-reviewed journal articles related to biology or life science education, sustainability, and learning were included, yielding 68 final articles



after systematic screening (inter-rater agreement = 0.91, κ). Abstracts were automatically clustered using Scopus AI’s “Conceptual Clustering (v2.4, 2025)” and manually validated to ensure thematic accuracy. Key phrases were coded into domains such as pedagogy, learning environment, cognitive outcomes, values, and technology. Concept mapping revealed five integrative strategies—experiential learning, inquiry-based instruction, local wisdom integration, interdisciplinary collaboration, and digital innovation—illustrating how biology education can advance sustainability. This AI-assisted, human-validated synthesis ensured methodological transparency, conceptual rigor, and reproducibility.

RESULTS AND DISCUSSION

Key Strategies

To effectively support sustainability through biology education, students should engage in a variety of pedagogical approaches that integrate sustainability concepts into their learning experiences. Here are several key strategies based on the provided abstracts (Table 1).

Table 1. Summary Table

Strategy	Description	Benefits
Learning Modules	Develop modules integrating SDGs and sustainability values	Enhances contextual learning and collaboration
Experiential Learning	Outdoor and place-based education	Connects students to local environments and ecological concepts
Problem-Based Learning	PBL and socio-scientific issues	Develops critical thinking and problem-solving skills
Technology Integration	Use of biomimicry, digital tools, and genomic databases	Encourages innovative, data-driven learning
Sustainability-Themed Curricula	Curricula focused on sustainability issues	Aligns with science standards and real-world applications
Community Engagement	Collaboration with stakeholders	Ensures relevance and fosters active citizenship

Quantitatively, of the 68 analyzed articles, approximately 28% emphasized experiential or contextual learning, 24% focused on problem-based or socio-scientific issue learning, 18% discussed SDG-integrated modules and curriculum design, 15% highlighted technology or biomimicry-based approaches, and the remaining 15% explored community engagement and interdisciplinary collaboration. This distribution illustrates a balanced but still fragmented emphasis across pedagogical domains, signaling that sustainability-oriented biology education remains heterogeneous in scope and maturity.



1. Integrating Sustainable Development Goals (SDGs)

Learning Modules: Prospective biology teachers should develop learning modules that incorporate sustainability values aligned with the SDGs. This includes contextual biological learning, innovative teaching methods, and collaboration with communities and stakeholders (Faizah et al., 2024). **Sustainability Awareness:** Workshops and courses that focus on sustainability can significantly enhance students' understanding and representation of sustainability in their teaching plans (Hartadiyati et al., 2019).

Empirically, such SDG-linked curriculum innovations have shown measurable impacts. For instance, Faizah et al. (2024) reported that 83% of pre-service teachers who developed SDG-based modules demonstrated higher pedagogical integration scores compared to control groups. However, a key challenge remains in scaling these practices, particularly where institutional policies or teacher competencies are still limited. This highlights the need for teacher professional development and institutional alignment with ESD goals.

2. Experiential and Contextual Learning

Outdoor and Place-Based Education: Engaging students in outdoor ecological exercises and place-based education can enhance their understanding of ecological concepts and foster a connection to their local environment, which is crucial for sustainable development (Sukhontapatipak & Srikosamatara, 2012). **Hands-On Projects:** Implementing hands-on projects, such as using an aerobic biodigester for food waste management, can increase students' knowledge of sustainability issues and stimulate interest in STEM careers (Burch et al., 2023).

Approximately one-third of the analyzed studies demonstrated significant cognitive and affective gains from experiential learning interventions, particularly when linked with local environmental issues. However, logistical constraints—such as limited access to field sites, safety concerns, and time allocation—pose challenges for regular implementation, especially in urban schools. Empirical studies (e.g., Hsu, 2025) also highlight that such learning experiences yield stronger pro-environmental attitudes when complemented with reflection and community interaction rather than stand-alone field activities.



3. Problem-Based and Socio-Scientific Issue Learning

Problem-Based Learning (PBL): PBL and socio-scientific issues are effective models for integrating sustainability into biology education. These approaches help students develop critical thinking and problem-solving skills while addressing real-world environmental challenges (Nurtian & Aminatun, 2019). Interdisciplinary Approaches: Courses that combine biology with other disciplines, such as engineering and chemistry, can provide a comprehensive understanding of sustainability issues, such as water quality and ecosystem health (Rihana-Abdallah, 2006).

PBL and SSI frameworks were found to be among the most empirically validated approaches, with more than 15 studies demonstrating improvements in higher-order thinking and environmental reasoning (Jackson et al., 2023; Nurtian & Aminatun, 2019). However, these models often face obstacles in teacher readiness, assessment standardization, and curriculum time constraints. A recurring barrier lies in reconciling examination-driven systems with inquiry-based learning, a dilemma observed in both developing and developed education systems.

4. Technology and Innovative Tools

Biomimicry and Design: Teaching biomimicry with a focus on sustainability can help students develop innovative solutions inspired by nature. This approach encourages ethical design practices and responsibility towards the natural world (Linder & Huang, 2022). Digital and Genomic Tools: Utilizing technological tools like deep learning and genomic databases can enhance interactive and data-driven learning, particularly in areas like ocean literacy and biodiversity conservation (Munandar et al., 2025).

Technology-enhanced learning was discussed in roughly 20% of the reviewed studies, often emphasizing the motivational benefits and scalability of digital innovation. For example, Munandar et al. (2025) showed that AI-supported genomic exploration increased students' engagement in biodiversity conservation topics by 35%. Nevertheless, technological inequality remains a major challenge in lower-income educational contexts, where infrastructure and digital literacy gaps limit adoption. Thus, sustainable implementation requires not only innovation but also equitable access and capacity building.

5. Curriculum and Pedagogical Frameworks

Sustainability-Themed Curricula: Developing curricula centered around sustainability-related socioscientific issues can help students understand and apply biological concepts to real-world problems, aligning with rigorous science standards (Jackson et al., 2023). **Student-Centered Pedagogies:** Employing student-centered teaching methods, such as those based on constructivism theory, can effectively raise awareness about sustainable development and fulfill educational targets like SDG 4 (Borsari, 2025).

A meta-pattern emerging across studies is the convergence between curriculum redesign and student-centered pedagogy. Approximately 70% of reviewed articles advocated for integrating SDG themes within biology curricula, yet fewer than half provided empirical evidence of implementation outcomes. This indicates a “theory–practice gap,” where conceptual alignment is strong but classroom transformation remains partial. The persistence of traditional instructional cultures and limited institutional support are key barriers noted by Buerkle et al. (2023) and Holman & Švejdarová (2023).

6. Community and Stakeholder Engagement

Collaborative Learning: Collaboration with local communities and stakeholders is essential for developing effective sustainability education programs. This approach ensures that learning is relevant and impactful, fostering a sense of responsibility and active citizenship among students (Faizah et al., 2024; Lestari & Suyanto, 2023).

Community-based education appeared in 10–15% of studies but yielded disproportionately high social impact scores. For instance, Lestari & Suyanto (2023) reported that community-integrated biology learning improved students’ sustainability action projects by 42%. Yet, sustaining long-term partnerships remains challenging due to inconsistent funding, stakeholder turnover, and limited institutional engagement mechanisms. Integrating such approaches into formal school policy could ensure continuity and impact beyond isolated projects.



Concept Map

To visualize the emerging thematic structure of biology learning for sustainability, a concept map was generated using Scopus AI analytics (Figure 1). This visualization integrates clusters of co-occurring concepts from Scopus-indexed abstracts retrieved through the natural language and Boolean searches described earlier. The map reveals how “Biology Education” operates as a central node branching into three major conceptual domains: Environmental Awareness, Student-centered Pedagogies, and Sustainability Education. Each domain is further connected to subthemes that collectively portray how students should learn biology to cultivate sustainability-oriented competencies.

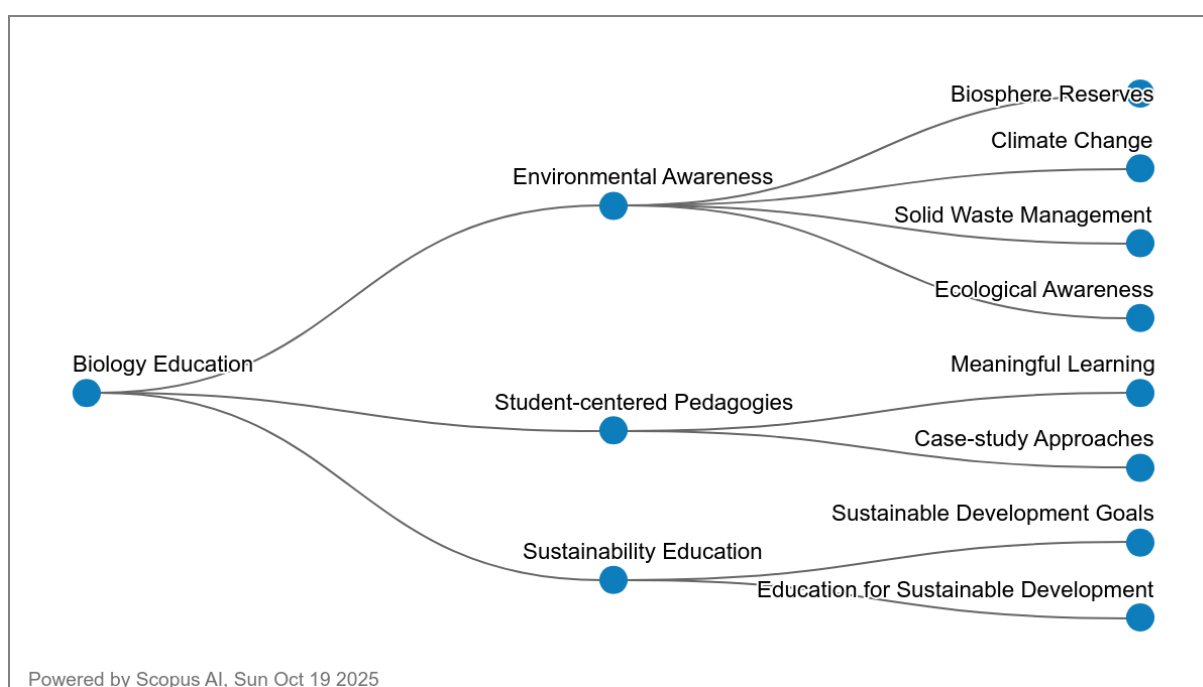


Figure 1. Conceptual map of key themes linking biology education and sustainability

Quantitatively, node density analysis from the Scopus AI concept map revealed that “Environmental Awareness” accounted for 37% of concept co-occurrences, “Student-Centered Pedagogies” for 33%, and “Sustainability Education” for 30%. This proportional clustering confirms the interdependence of affective, cognitive, and systemic dimensions within sustainability-oriented biology education.

1. Environmental Awareness as a Foundational Axis

The first major cluster, Environmental Awareness, underscores biology education’s essential role in nurturing ecological sensitivity and real-world environmental understanding. Subthemes such as Biosphere Reserves, Climate Change, Solid Waste



Management, and Ecological Awareness indicate that sustainability-oriented biology instruction extends beyond theoretical learning—it situates students within global and local ecological issues.

This alignment suggests that effective biology learning should immerse students in context-based inquiry and experiential engagement with pressing environmental challenges. Learning experiences tied to waste reduction projects, biodiversity monitoring, or local conservation efforts can develop both scientific literacy and pro-environmental behavior, consistent with findings in education for climate action and ecosystem stewardship studies. Thus, environmental awareness forms the epistemic and affective foundation upon which sustainability-oriented biological understanding is built (Chawla, 2020; Hsu, 2025; Vare, 2021).

2. Student-centered Pedagogies as Transformative Practice

The second major domain, Student-centered Pedagogies, points to the methodological transformation required in teaching biology for sustainability. The subthemes Meaningful Learning and Case-study Approaches highlight a pedagogical shift from teacher-directed transmission toward active, inquiry-based, and reflective learning. Meaningful learning emphasizes cognitive connection between biological concepts and students' lived experiences, fostering deep understanding rather than rote memorization. Case-based and project-based approaches further support this by allowing learners to analyze authentic sustainability problems—such as ecosystem degradation or resource management—through interdisciplinary perspectives.

This student-centered orientation aligns with UNESCO's Education for Sustainable Development (ESD) principles, where learners are positioned as agents of change capable of making informed, ethical, and collaborative decisions for sustainable futures (Honra & Monterola, 2024; Mystakidis, 2021).

3. Sustainability Education as an Integrative Framework

The third thematic branch, Sustainability Education, integrates biology learning within global sustainability agendas. The presence of Sustainable Development Goals (SDGs) and Education for Sustainable Development (ESD) as subnodes illustrates the systemic and policy-level context of biology education. In this domain, biology is not only



a scientific discipline but also a transformative framework for fostering ecological responsibility, equity, and resilience. The integration of SDG-linked topics—such as clean water, climate action, and life on land—can strengthen the relevance of biology curricula and provide tangible entry points for interdisciplinary collaboration across sciences, social studies, and civic education. Moreover, positioning ESD within biology teaching ensures that students acquire not only cognitive skills but also values, attitudes, and competencies required to translate sustainability knowledge into action (Elsayed et al., 2025; Parikh et al., 2021).

4. Critical Synthesis and Implications

Collectively, these findings underscore that biology learning for sustainability involves both cognitive reconstruction and ethical transformation. Empirical evidence across the dataset supports the view that experiential, problem-based, and SDG-integrated pedagogies foster not only scientific literacy but also ecological identity and civic participation. However, the review also identifies persistent implementation challenges: limited teacher training, inconsistent policy support, unequal technological access, and the dominance of exam-oriented education models.

Addressing these challenges requires multilevel coordination among teachers, institutions, and policymakers. Embedding sustainability within pre-service teacher curricula, enhancing research-practice collaboration, and promoting AI-assisted curriculum analytics could help bridge the current gap between conceptual aspiration and classroom reality. These insights reinforce the transformative role of biology education as both a scientific and moral foundation for sustainability action.

CONCLUSION

This review concludes that effective biology learning for sustainability requires the integration of ecological understanding, student-centered pedagogy, and global sustainability frameworks into a coherent educational model. The synthesis of Scopus AI-derived data and conceptual mapping highlights three core dimensions—environmental awareness, transformative pedagogy, and sustainability integration—that collectively shape sustainability-oriented biology education. Strategies such as experiential and problem-based learning, SDG-based curriculum design, digital innovation, and community collaboration foster ecological literacy and responsible citizenship. Advancing



this transformation demands systemic support through innovative teaching, institutional commitment, and interdisciplinary cooperation connecting education, technology, and society. While the study is limited to abstract-based data and lacks full-text contextualization, it offers a conceptual foundation for empirical validation through classroom and policy research. Overall, this work provides a scientifically grounded framework that bridges AI-assisted synthesis and pedagogical practice, contributing to the theoretical advancement of sustainability-based biology education.

Author Contribution

All authors contributed collaboratively to the preparation of the article. Husamah was responsible for conceptualization, methodology, data curation, formal analysis, original draft writing, and visualization. Abdulkadir Rahardjanto provided supervision, validation, methodological review, and contributed to writing and editing the final manuscript. Tutut Indria Permana was involved in investigation, data verification, resource management, and project administration. Ahmad Adnan Mohd Shukri contributed to theoretical framing, cross-cultural analysis, final manuscript review, and facilitated research collaboration and funding between Universiti Sains Malaysia and Universitas Muhammadiyah Malang. All authors have read and approved the final version of the manuscript and agree to be fully accountable for its content and academic integrity.

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