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INTRODUCTION

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INTEGRATING ECO-PEDAGOGY AND GREEN TECHNOLOGIES TO TRANSFORM BIOLOGY TEACHER EDUCATION FOR SUSTAINABILITY

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Abstract
The mounting environmental challenges which include climate change and biodiversity loss have underscored the pressing need for innovative educational practices that advance environmental understanding and sustainable living. Biology education possesses an essential part in this activity, especially through the advancement of future teachers who are prepared to instil values of environmental responsibility. This paper examines the integration of eco-pedagogy and green innovations as a synergistic approach to changing science educator instruction with regard to sustainability. This paper scrutinises the potential of biology teacher education programme in rebuilding sustainability through innovative educational techniques such as inquiry-based learning, project-based learning, and open-air instruction. The paper highlights the importance of green technologies such as virtual laboratories, augmented reality applications, artificial intelligence tools and environmentally sustainable laboratory practices in mitigating the ecological footprints while enhancing pedagogical effectiveness. The paper addresses insufficient infrastructure, teacher resistance, and administrative impediments as some of the challenges of integrating eco-pedagogy and green technologies. It concludes with key proposals for integrating sustainability into teacher education programmes, arguing that the integration of eco-pedagogy with green innovations presents a compelling road map for realising education for feasible improvement and advancing worldwide targets such as SDG 4 (Quality Instruction) and SDG 13 (Climate Activity).

Keywords: Eco-pedagogy, Green technologies, Biology education, Teacher training, Sustainability, SDG, Environmental education, Critical pedagogy

Introduction

A critical juncture in the history of humankind with two survival crises that are fundamentally transforming our life on Earth: catastrophic loss of biodiversity and accelerating climate change. They are not two separate crises but closely interrelated emergencies, both emanating from human's consistent destabilization of nature through unsustainable use, pollution, and land cover changes. The ramifications extend far beyond ecological harm because they are destabilizing the very ecological foundations of human civilization, from the security of water and food to climate protection and disease control. The roots of our status lie in the environmental awareness of mid-20th century initiated by the title of the paper Silent Spring by marine biologist and conservationist Carson (1962). The paper served as a clarion call, showing how unchecked pesticide application was leading to disastrous ecological cascades, from silent birdless springs to contaminated watersheds. This pioneering criticism provoked an unprecedented amount of public activity, generating landmark events like the initial Earth Day in 1970, when 20 million Americans marched - and the 1972 UN Conference on the Human Environment in Stockholm, the initial big international conference on environmental issues. Brundtland's report in 1987 formalized the intellectual framework for addressing these issues. The world report spelt out the concept of sustainable development while referring to it as "development that satisfies the current needs without endangering the ability of future generations to satisfy their own future needs" (WCED, 1987). The visionary report set a conceptual framework for the Rio de Janeiro Earth Summit in 1992, where Agenda 21 was drafted as a global blueprint for sustainable development, with education given a core role in its actualisation.

The Evolution of Eco-Pedagogy: From Critical Consciousness to Planetary Praxis

In this period of environmental awareness, concurrent with an educational revolution, emerged the eco-pedagogy movement as a revolutionary approach to environmental education was unfolding. The movement took Freire's (1970) radical critical pedagogy of critical consciousness and liberatory learning forward. Groundbreaking scholars like C.A. Bowers (2001) and Richard Kahn (2010) expanded upon the work of Freire, to what we now recognize as modern eco-pedagogy which is an educational theory that:

1. Overturns the dominant anthropocentric world view and its ill-conceived separation of humans from nature
2. Unveils political-economic drivers of environmental degradation, and
3. Allow learners to become systemic agents of change through place-based, experiential learning

This is a radical break with the old environmental education, which eco-pedagogues are critical of as being overly mechanistic, depoliticized, and complicit in reinforcing unsustainable status quos. Rather, eco-pedagogy requires uncovering uncomfortable

truths regarding how ecological crises overlap with colonialism, capitalism, and social injustice, what scholar David Orr has termed "the myth of human exemptionalism.

The Green Technology Revolution: Practical Solutions Meet Systemic Change

Then came the late 20th century, which brought with it a revolutionary transformation, the Green Technology Revolution. It was no longer a matter of ideas; real-world practical applications began tackling the growing environmental problems. This represented the very beginning of the green tech revolution, and with it came a new set of exciting innovations, all aimed at fixing the world's woes and healing the planet. Solar panels appeared on rooftops, while the sounds of wind turbines greeted us along the hills, and geothermal energy drilled into the earth for its heat. Farmers adapted their fields to agroecology and permaculture, in other words, working with nature rather than against it. The idea of a circular economy also emerged, in which resources were used in smarter, waste-free ways. Cities and industry got a green makeover. Parks replaced concrete, buildings mimicked nature's brilliance, and urban planners finally started listening to the wisdom of ecosystems. Gradually, a new type of thinking, one that respected the planet we call home, developed. Such practical solutions were backed by policy at international levels through agreements like the 1997 Kyoto Protocol and 2015 Paris Agreement, while UNESCO's Education for Sustainable Development (ESD) initiative aimed at incorporating concepts of sustainability into the world's education systems (UNESCO, 2017).

Toward a Transformative Model of Biology Teacher Education

In an eco-pedagogy, the education of biology teachers must be transformed. Traditional approaches which focus so narrowly on content coverage and standardized assessment are woefully inadequate to prepare students to respond to our complex planetary crises. We need teachers who can: Ecological literacy that unfolds the interconnected systems (e.g., how melting Arctic Permafrost releases methane, which in turn is the main driver of global warming) should be taught; Critical consciousness, which is one of the root causes of environmental degradation should be developed in the students; develop pedagogical strategies that link theory and practice, Combining the critical emphasis of eco-pedagogy and the solution seeking pragmatism of green technology education creates vibrant learning experiences in which students can: Conduct biodiversity surveys of local ecosystems while learning about policy frameworks that protect (or endanger) these environments; Create sustainable food systems projects that address ecological and food justice issues; Engage in citizen science projects tracking climate impacts in their communities.

These types of approaches stretch from abstractions to cultivate what scholar David (1999) calls "ecophilia", an affective appreciation of the living world that motivates

stewardship.

When students engage with the real-world scenarios of deforestation-climate feedback loops in the tropical rainforest or socio-ecological processes of urban heat islands, they develop knowledge and moral imagination as the very antecedents of transformational action. But rethinking teacher training is necessary for transformation to occur. Change in teacher training begins with the curricula that needs to be rewritten with programs that encourage systems thinking and show the inseparability of society and environment. There is also the need to change the assessment methods beyond mere memorizing of content to one that looks at critical thinking and problem-solving in the real world. Finding a connection between schools and the communities around them can actively bind the abstract theory to real environmental issues that students face. Teachers themselves need continued support in the way of professional development so that they're capable of bringing sustainability education to life in their classrooms.

Learning biology must shift from passive uptake of information to active engagement with our global emergency. Educating teachers and students both with ecological literacy, critical sensitivity, and practical competencies for change, can develop leadership needed to guide and maybe redefine humanity's present self-destructive course on. It is less a matter of saving ecosystems together, than it is re-visioning the ways the classroom confronts its students with the troubling realities associated with ecological breakdown, and how they might think of themselves collectively as co-creators of more just, sustainable futures.

Global and Local sustainability challenges- Climate change, Biodiversity loss and socio-environmental conflicts in Nigeria

The world is undeniably at a turning point in human history, and we face what scientists categorize as a "triple planetary crisis" (climate change, loss of biodiversity, and pollution) (UNEP, 2021). Recently, the IPCC (2023) report demonstrates that 1.1°C of warming above pre-industrial levels has occurred globally due to anthropogenic greenhouse gas emissions primarily associated with fossil fuel combustion and land-use change. This trend of warming is expressed in more frequent and intense climate disturbances, ranging from record wildfires and extended droughts to more powerful tropical storms and speeding sea level rise - that are inherently reshaping Earth's ecological equilibrium. At the same time, scientists are also registering that we are experiencing what is likely to be the sixth mass extinction of species on Earth. Helpful here is the IPBES (2019) Global Assessment Report is particularly useful that consolidates evidence from researchers and institutions from around the world, clearly shows that "up to 1 million species of plants and animals are now threatened with extinction within the next few decades" unless "transformative change" across a varying severity and effectiveness of conservation measures is taken. Vertebrate populations have already declined to an

alarming 69% since 1970 (WWF, 2022), and human activities have altered approximately 75% of terrestrial ecosystems and 66% of marine ecosystems. These alterations to ecosystems can also severely impact essential ecosystem services that are key to human well-being such as, pollination, water purification, soil formation, and climate regulation (Cardinale, *et. al.,* 2012).

The intersecting pressures of climate change and biodiversity loss lead to a web of feedback. Land degradation and forest loss specially yield carbon, reduce ecosystems' potential to serve as carbon sinks which contribute to global heating (Pörtner et al., 2021). Climate heating and variability, further, fundamentally alter species' life cycles, patterns of migration, and ecological relationships through nonlinear phenological changes (Hoegh-Guldberg *et. al.,* 2018). The financial implications are huge, for instance the Dasgupta Review (2021) estimates biodiversity loss alone costs around $25 trillion per year in lost ecosystem productivity and additional exposure to natural hazards. The effects of biodiversity loss and climate change are profound inequities, which are always heavily UV-biased against poor peoples in the Global South who are disproportionately reliant on ecosystem services for their livelihoods and food security (Rockström *et. al.,* 2023). This is a fact that demonstrates the need to embrace sustainability measures that intertwine environmental protection with social justice principles, particularly in teacher training programs that will educate generations to come on these complex issues.

Herder-Farmer Conflicts in Nigeria as Microcosm of Global Challenges

Environmental degradation and social violence are intimately connected as illustrated by the ongoing herder-farmer conflicts in Nigeria, which are escalating particularly in its Middle Belt region but extending to nearly all parts of country. The conflicts are a classic instance of climate change as a threat multiplier in fragile socio-ecological systems. Desertification in northern Nigeria, along with the southward spread of agricultural settlements, has narrowly constricted traditional transhumance corridors used by predominantly Muslim Fulani pastoralists for centuries. Meanwhile, mostly Christian farming communities face similar challenges of soil fertility decline and irregular rainfall. What began as a simple difficulty of limited natural resources has expanded significantly into a more complex crisis that relies heavily on ethnic, religious, and political factors. Tensions of this nature are commonly exploited by politicians when they transform local resource conflicts into full blown conflicts, which have resulted in multiple thousands of deaths, significant mass internal migration in the region, and severe disruptions to local economies. There are always underlying socio-economic circumstances that can complicate efforts to resolve the current situation, such as youth unemployment, poverty and weak governance institutions. The environmental impact is similarly dire, as this sort of conflict can accelerate land degradation and loss of biodiversity in affected areas which can potentially lead to a self-reinforcing

process of ecological and social decline.

The Critical Role of Biology Education in Developing Ecological and Socio-Political Consciousness

Biology education is especially significant as a possible source of both ecological literacy and social change. Conventional approaches to biology education, which emphasize decontextualized abstract ideas and steps, are inadequate for bringing about solutions to these contemporary sustainability problems. Research reveals the significant benefits of transformative, place-based pedagogies that develop ecological literacy through students' critical systems thinking ability (Hart, 2007; Wals, 2010). Experiential learning activities are particularly effective at developing environmental awareness and ecological identity through field-based inquiry, outdoor education programs, and community-based projects (Sobel, 2004; Ernst & Monroe, 2006). Reflective practices such as ecological autobiographies, sustainability-themed action research, and critical incident journals can support pre-service and in-service teachers' exploration of their own values and assumptions about the nature/human relationship (McKenzie, 2008). Each of these instances of reflective practice is aligned with more current models of environmental education, such as Hungerford and Volk's (1990) model for environmental literacy and Wiek *et. al's.* (2011) key competencies for education for sustainability that promote systems thinking, anticipatory and normative thinking, strategic action, and problem-solving with others. Effective education for sustainability incorporates these models and the practices in such a way that they can be directly applied to a local social and ecological context. For instance, in Nigeria, biology education programs could integrate case studies of herder-farmer conflicts that would enable students to consider the interrelationships between competing claims to resources, environmental stressors, and identity politics. This case study would reflect the relevant emerging trends in how science education is starting to engage in socio-scientific issues, in which a socially controversial, real-world dilemma is used as a context within which students can grow and develop their scientific literacy and ability to think critically about the ethical and social consequences of science and its advancements (Zeidler *et. al.,* 2005; Hodson, 2003). Context embedded learning experiences can help students recognize how large-scale realities such as climate change are articulated in locally contextualized ways, while also developing the analytical skills needed to negotiate and level competing claims and competing perspectives. Furthermore, this approach builds on and opens a departure from reductive "either/or" depictions of environmental conflict to invite students learning about the diverse, tangled connections between ecological, biophysical, and cultural considerations that contribute to sustainability considerations.

It is essential to prepare teachers for this broader role and require comprehensive changes in teacher training programmes. Classical models often fail to equip teachers with interdisciplinary information and pedagogical skills that would allow them to address challenges of sustainability properly. Research has indicated that integrating sustainability themes into teacher preparation programs, rather than treating them as separate electives, significantly enhances teachers' self-efficacy and commitment to sustainability education (Biasutti & Surian, 2012; Sahin *et. al.,* 2012). Key elements of this transformation are: Enhancing teachers' understanding of ecological systems, climate science, and the socio-political dimensions of sustainability; Enhancing pedagogical approaches for facilitating challenging discussions of environmental justice and conflict resolution; Establishing partnerships with local communities and environmental organizations to create legitimate learning opportunities; Establishing models of ongoing professional development that support teachers' ongoing learning as sustainability educators.

Collaborative pedagogies, like professional learning communities and mentorship-based induction programs, have been particularly effective at enabling teachers to learn and refine sustainability-focused pedagogies (UNESCO, 2017). These collaborative structures make it possible for the co-construction of novel teaching practices in addition to emotional and professional aid for teachers navigating these complex, often emotional challenges.

Innovative Pedagogies for Sustainability Competence

Transformative sustainability education requires a move away from traditional lecture-style teaching to engaging, participatory learning strategies. Active learning projects that engage students in searching out local environmental issues or designing sustainability solutions have been very useful in developing action competence (Mogensen & Schnack, 2010). Similarly, systems thinking exercises that map the interconnections of ecological, economic, and social factors facilitate the understanding of the intricacy of sustainability problems by learners. Hands-on approaches like ecological footprint analysis, citizen science, and sustainable school projects provide concrete avenues through which students can put theoretical ideas into practice with the gaining of hands-on abilities (Shephard *et. al.,* 2012). Authentic learning environments like school gardens, nature parks, and local sustainability projects facilitate greater student engagement and more effective learning linkages to immediate settings (Evans *et. al.,* 2017). In the Nigerian context, these approaches could involve students in the activity of restoring habitats, conservation of water, or community forums on resource management - all while developing core biology capabilities and knowledge.

Understanding Eco pedagogy

The environment is the pillar of support for important resources such as air, water,

land, and raw materials, essential for human subsistence and development. Nigeria, like many countries globally, is confronted with grave environmental challenges. Some of which emanated from lack of awareness, widespread poverty, rapid population growth, unchecked greed, relentless and unsustainable use of natural resources etc., resulting in ecological decadence.

The significant impact of the environment on sustainable development had necessitated the need for more awareness of all the stakeholders on the responsible use of environment and natural resources, for conservation and sustainability. This has been substantiated with studies, one of which was conducted by (Okon *et. al,* 2021). It could be inferred from their review that there is the need to intensify efforts on research involving the impact of climatic change on aquatic bodies, and their sustainability. The need to have all-inclusive research, devoid of regional segregation among others was also upheld. These are some of the strategies that could be adopted in mitigating the environmental challenges emanating from our actions.

Human activities have resulted in environmental challenges ranging from social, economic, political and environmental. This consequently has a detrimental impact on the inhabitants of the atmosphere. The influence of environment on human health is being ignored globally, with densely populated countries like Nigeria more vulnerable. This is often reflected in the persistent problem of air and water pollution, ozone depletion, among others. This global problem requires an urgent attention across the countries to meet up with the transformation agenda of the United Nation. Hence the need to understand what eco pedagogy entails. Eco pedagogy is sometimes referred to as environmental education. It has been a common and universal concept of discourse since 1990's. Misiaszek (2015) viewed eco-pedagogy as a form of environmental education and education for sustainable development. Hung (2023) described eco pedagogy as being concerned with pleasant human-nature relationships.

Eco-pedagogy implies harmonious coexistence between nature and humans. It involves living in an environment without causing harm to the living and inanimate objects within the surrounding. It stressed the need to be aware, take an active role in conserving and making inform decision on virtually everything in the community. sustainable development. Eco-pedagogy is an educational approach and a movement towards social change and better environment (Amaliati, Rusydiyah & Abu Bakar, 2024). It is an all-encompassing practice that everybody, irrespective of the discipline, must practice.

Misiaszek (2015) defined eco-pedagogy as the educational approach that connects the teaching and learning to environmental and social problems for sustainability. It is an integrated and engaging means of involving individuals, societies and natural

worlds. Monen (2024) also described eco-pedagogy as the interconnectedness between people and the earth. This is corroborated by the description of Hung (2025) who also affirmed that eco-pedagogy establishes the relationship between human and 1) earth 2) nonhuman 3) nature and) world. It could be inferred from this definition that all and sundry must realize the fact that human actions are influenced by the environment and vice versa; and mutually exclusive.

Hung (2025) identified two parts of eco-pedagogy as micro and macro, i.e., it must be approached from local and global practices for transformative agenda to be achieved. Micro perspectives contextualised learning by embarking on several hands on, experiential learning for environmental awareness. The macro framework on the other hand highlighted the need for globalizing environmental education for human experiences, values and relationship with the environment. This must be done holistically by exploring complex relationships between human and the environment. This buttressed the assertion of Ogunkan (2022) that a joint effort and broader review are key to environmental management and sustainability that the world is craving for.

The theory behind eco-pedagogy must be understood by everybody irrespective of the race, gender and specialty. Eco-pedagogy must be used in conjunction with other strategies for students understanding and for solving local and international problems. An in-depth understanding of eco-pedagogy had the tendencies of alleviating most of the socio, political, financial and economic challenges confronting air, environment, water and other necessities of human. Policy has been put in place and research is conducted to alleviate the problems and achieve sustainable development. For instance, Ogunkan (2022) ascribed Nigerian environmental challenges to feeble establishment framework, non-enforcement of laws and implementation. These problems could be ameliorated by good governance, clear and execution of environmental laws and institutional framework and environmental governance. These are ways of ensuring peaceful coexistence between humans and nature, i.e., eco pedagogy.

In a like manner, Adeoti *et. al.,* (2023) conducted a systematic review on water infrastructural sustainability in Nigeria. Their study discovered that sustainable water infrastructure is being hindered by several factors such as procedural, monetary, environmental, social, political and institutional. The study recommends a stage-by-stage framework for water sustainability and highlighted the need for a structured and detailed tactic for sustainability. Going by these multifaceted challenges, a collaborative approach to problem solving should be adopted. All the principal stakeholders should be involved in addressing the problem for upmost results.

Transforming Biology Teacher Education Programmes through the Merger of Eco-Pedagogy and Green Technologies to Reform Biology Teacher Education for Sustainability

To produce graduates that are environmentally conscious and highly motivated to ensure the sustainability of nature, there is the need to transform the biology teacher education programme to meet the yearning needs of the 21st Century Biology teacher. These can be achieved through.

1. Re-Design Curriculum to Reflect Sustainability Themes

Transforming biology teacher education to include the principles of sustainability is a comprehensive curriculum change. The change must weave environmental, social, and economic dimensions of sustainability into existing core courses, not as add-ons. Curriculum designs must emphasize systems thinking, reflective critique, and solution application of sustainability problems. Such integration will ensure that future teachers are equipped to teach future students to handle complex global issues like climate change, biodiversity loss, pollution, and environmental justice.

UNESCO's (2024) greening curriculum framework suggests teacher education institutions follow a ten-step process that includes needs analysis, stakeholder engagement, piloting, and staff development. A curriculum with the theme of sustainability strengthens inter-disciplinarity and builds the ability of students to consider the long-term consequences of scientific, technological, and societal endeavors.

Furthermore, the inclusion of local environmental and social contexts lends relevance and encourages community engagement. For example, case studies and examples of environmental issues such as erosion, floods, desertification, or deforestation by region allow trainee teachers to relate scientific content to daily applications and solutions. There is also a need for curricular emphasis on participation, ethics, and equity to prepare future teachers to recognize as well as challenge unsustainable systems and practices in and outside their communities.

2. Employing the Right Pedagogical Strategies

2.1 Project-Based and Inquiry-Based Learning (PBL/IBL)

Inquiry-based learning (IBL) and project-based learning (PBL) are central pedagogical approaches to incorporating sustainability in teacher education. IBL engages future teachers to pose questions, investigate real-world issues on the planet, and form evidence-based solutions. PBL allows them to work on extended projects that draw upon the learning from many disciplines, promote collaboration, and produce tangible products that can be used for

addressing school or community-level environmental issues.

These student-centered approaches encourage critical and creative thinking, deepen content knowledge, and foster 21st-century skills such as collaboration, communication, and self-regulation. In teaching biology, for instance, teacher candidates can design projects on sustainable farming, conservation of biodiversity, waste disposal, and water purification. Guided inquiry enables them to learn how to connect abstract biological concepts to environmental and social phenomena, thus making biology more relevant to everyday life and sustainability challenges.

2.2 Garden-Based and Outdoor Education

Garden-based and outdoor education are excellent ways of placing biology and sustainability education. They offer experiential, hands-on learning spaces where trainee teachers experience nature firsthand, promoting observation, exploration, and enjoyment of nature. These methods enable future teachers to learn ecological concepts, life cycles, species interaction, and care for the environment in context.

School gardens, for example, are outdoor classrooms through which biology content such as photosynthesis, soil, plant reproduction, and composting can be explored. Through planning, maintaining, and learning about plant and animal life, teacher candidates both gain content knowledge and pedagogical skills to oversee and implement outdoor learning in lesson plans.

Further, such activities have emotional and social dividends, promoting students' relationship with nature, physical education, as well as responsibility and cooperation. Outdoor education is particularly well-suited to cultivate environmental dispositions, empathy, and sustainability values.

2.3 Eco-Pedagogical Framework

Eco-pedagogy refers to a radical pedagogical movement that blends ecological literacy, social justice, and critical pedagogy. It centers on the interdependence of human beings and nature, learning from exploitative systems, and encouraging responsible citizenship and ecological agency.

In accordance with Paulo Freire's and critical theorists' writings, eco-pedagogy invites teacher educators to move beyond content transmission to participatory, dialogic, and action-based learning. In the case of biology teacher education, eco-pedagogy invites future biology teachers to study how science is intertwined with sustainability issues such as the use of natural resources, environmental destruction, climate change, and hunger. Eco-pedagogy also raises awareness about power relations and unequal structures producing these issues.

An eco-pedagogy framework calls for the integration of service learning, interdisciplinary projects, reflective criticism, and activism into educational practice. It provokes students to imagine and create educational practices that promote ecological integrity, moral responsibility, and sustainable futures.

3. Integration of Green Technologies

The use of green technologies in biology teacher education brings new opportunities for the promotion of sustainability and inquiry-based science education. Green technologies refer to those environment-friendly equipment, systems, and innovations that reduce environmental burden, conserve energy, and promote sustainable development.

Student teachers can be introduced to such technologies as microbial fuel cells that generate electricity from organic wastes or biofilters applied in water recycling. They are not teaching aids but real applications of biological principles. Introducing them to green nanotechnology, e.g., use of biogenic nanoparticles for detecting pollution - demonstrates how emergent technologies are applied to address threatening environmental problems.

By adopting the Science – Technology – Society – Environment (STSE) model, teacher education programs can situate scientific advancement within environmental, cultural, and ethical contexts. Thus, prospective biology teachers are equipped to critically examine technology's role in sustainability and foster innovative student thinking in science-based solutions to environmental challenges.

Case Studies and Pilot Programs that Demonstrates the Effect of Eco-pedagogy and Sustainability Practices

Some good case studies demonstrate the effect of eco-pedagogy and sustainability-oriented practices in biology teacher education:

- Brazilian PIBID Composting Pilot: Trainee biology teachers led composting activities at public schools through this initiative. They acquired skills to teach lessons on decomposition of waste, recycling, and soil ecology while promoting environmental awareness among the students. Through this hands-on activity, they could acquire skills to teach science from a perspective of sustainability.

- Angolan ITE for SDGs: An Angolan pilot integrated SDG content into pre-service teacher preparation. Future biology teachers selected research areas that targeted local social and environmental issues, such as deforestation and water access. Though there was meager curricular guidance, their activities demonstrated sincere concern about sustainability issues.

- University Transdisciplinary Module: A 16-week transdisciplinary project among students from education and the wood-processing faculty to address sustainability issues in their home community. The course attested higher systems thinking, communication, and sustainability management competencies, respectively, among the students.

  These programs confirm the necessity of transdisciplinary interaction, experiential learning, and community involvement in the education of biology teachers in preparing for education for sustainability. Incorporate Eco-Pedagogy and Green Technologies to Transform Biology Teacher Education for Sustainability

Considerations of Biology Education: Human Augmentation

Integrating Technology to Enhance Biology

Consider students interacting with biology actively as opposed to passively learning via texts. Picture students engaging with hands-on interactive simulations and actively resolving environmental issues. Students can try out different decisions and gauge the results of their decisions via simulations. Such simulations can make biology learning feel pertinent and engaging (Scalise & Gifford, 2009).

Analyzing Performance: Opportunities for Individualized Learning

Tracking data and performance in current educational systems enables identifying learning gaps, adapting classes to individual students, and addressing their specific requirements (Spector & Park, 2018). Such methods ensure customized learning trails for every student.

Africa's Distinct Chances and Problems

The Digital Divide

Access to the internet and reliable digital devices remains the most notable challenge for many learners in Africa, as discussed by Isaac and Michael (2017). Without addressing this most fundamental concern, there is little hope seeking to universalize these advanced pedagogical approaches.

Empowering Educators

Educators need professional development and continuous mentorship to optimize and fully benefit from these advanced pedagogical tools. They must feel empowered and understand the method of infusion, or how to include technology in lessons for its intended purpose (Kezar & Gehrke, 2015).

Shortcomings of Conventional Teaching Approaches

Emphasis on Recall Rather Than Understanding

Traditional tests focus on rote learning and recalling biology, and the focus is on the subject's factual aspects in isolation instead of on how it is intertwined with the larger

ecosystem (Momsen *et. al.,* 2010).

Slow and Limited Feedback

Traditional tests tend not to provide students with prompt feedback. But in learning about complex systems, as with how ecosystems function - having immediate feedback is crucial to really understanding the information (Sadler, 2009).

Missing Real-World Connections

When biology is presented in isolation, the story gets lost and students don't even get to see how it relates back to things like sustainable farming or renewable energy." This divergence can lead to the perception of science as less relevant(Zeidler et al., 2005).

How Adaptive Technology Can Help

Learning That Fits Local Needs

The lesson can be adapted by the system to meet individual backgrounds of students as well as environmental issues they are facing. For example, some students come from a coastal community so they might be dealing with marine conservation while others hail from dry lands thus relating them in discussion about water conservation measures (Kearns 2018).

Building Knowledge Step by Step

These tools introduce subjects step by step, starting with basics and moving toward advanced topics, like biotechnology (Plass *et. al.,* 2020).

Immediate Help to Solve Issues

With immediate feedback, students are able to correct mistakes immediately and delve deeper into learning complex topics, like bioenergy or cleaning pollution (Shute, 2008).

Improved Methods to Assess Learning

Adaptive tests can change their difficulty level in line with the performance of a student so that they give an actual picture of what they really know about sustainability (Bennett, 2015).

Green Technology in the Classroom

Virtual Simulations: Students can try out environmental solutions in virtual environments. For instance, they can model how wetlands clean water and support wildlife (Scalise & Gifford, 2009; Hmelo-Silver *et. al.,* 2007).

Online Biotech Labs

Virtual labs let learners try out new projects on things like eco-friendly plastics or gene changes even if the school does not have an in-class lab (de Jong *et. al.,* 2013).

Real-World Tools

Using tools like carbon footprint calculators, students can see for themselves how biology is connected to sustainability and the choices we make on a daily basis (Kollmuss & Agyeman, 2002).

Adding adaptive technology to the classrooms of African biology students has the ability to transform the manner in which students learn, allowing classes to be more accurate, tailored, and interactive. There are still challenges, including access and teacher training, but the possibility for generating environmental literacy and hands-on knowledge is worthwhile by attempting it by teachers, policy makers, and academics.

Benefits and Impacts of Eco-Pedagogy and Green Technologies

a. Environmental Awareness and Responsibility

Eco-pedagogy enriches ecological literacy and enables students to understand and respond to ecological problems with critical as well as practical skills It inculcates in learners, a culture of concern for the environment and sustainability in students' everyday lives (Intsiful, Intsiful & Boateng 2025).

b. Language and Environmental Integration

Green pedagogy integrates with English as a Foreign Language (EFL) class in such a way that students get a chance to improve their language skills and become environmentally minded at the same time. Utilizing green topics for reading, writing and speaking a learner enhances English skills and gets to the bottom of the environmental problems (Hossain, 2019).

c. Curriculum Enrichment and Skills Development

The introduction of environmentally friendly concepts in the higher education sector equips graduates with the necessary skills for the "green jobs" market and allows them to respond to the industries' needs, especially in the areas of sustainable construction, renewable energy, and climate science. It makes students more employable and links their education to the sustainability mission (Abeyrathna, 2021).

d. Promoting Sustainable Living and Global Citizenship

Eco-pedagogy changes students' lives by embedding such moral values of global responsibility, social justice, ethical treatment of nature. It sparks the imagination of learners as they themselves go about effecting sustainable change and additionally challenges the practices that are economically exploitative (Intsiful *et. al.,* 2025).

e. Experiential and Transformative Learning

Learning through the five senses, hands-on style such as gardening, green projects, and outdoor classroom activities has been significantly stressed upon by eco-pedagogy. It thus helps to fill the gap between the theory and the practice of the environmental discipline by arousing interest and making the retention a possibility (Hossain, 2019; Misiaszek, 2020, as cited in Intsiful *et. al.,* 2025).

f. Technological Innovation and Eco-friendly Solutions
Green education is undoubtedly the implementation of clean technologies, nanotechnology and digital tools that not only protect the environment but also make more efficient use of resources and support education that is environmentally sound (Aithal & Rao, 2016, as cited in Abeyrathna, 2021).

Challenges of Eco-Pedagogy and Green Technologies

a. Limited Curriculum Integration and Policy Support
Across the world, environmental content is hardly there in the curriculum, and leakage occurs in policy structure. Sustainable education in traditional schooling is not recognized as interdisciplinary in nature (Hossain, 2019; Intsiful *et. al.*, 2025).

b. Awareness and Conceptual Gaps
There is a very low level of awareness of green pedagogy among the teacher force, and students. Unfamiliarity with the idea and its potential role in the education systems is the main issue raised among educators and students (Hossain, 2019).

c. Resource and Infrastructure Constraints
Green education implementation constantly necessitates certain resources, some of which include green technologies, teaching materials, practical facilities among others that are not available or are very limited in quantity and hence high in price for many institutions especially those ones in developing countries (Abeyrathna, 2021)

d. Theoretical and Practical Disconnect
While sustainability is a very popular topic discussion goes, there is often a gap between theoretical knowledge and practical implementation, limiting learners' ability to bring about real change (Intsiful *et. al.,* 2025).

e. Political and Institutional Resistance
Green education is not welcomed by educational and economic neoliberal systems that are deeply embedded. Educational policies are often loopholes for the superficial changes that are in line with politics, rather than environmental transformation. (Intsiful *et. al.,* 2025).

f. Limited Research and Undefined Frameworks
The field is without major frameworks and has scarce empirical research, which brings about conceptual ambiguity and the non-uniformity of implementation (Abeyrathna, 2021).

The Role of Eco-Pedagogy and Green Technologies in Education Eco-pedagogy and green education are pivotal in planting the environmental consciousness and in the promotion of sustainable practices.

Benefits and Impacts

1. To foster mutual learning and the exchange of best practices in environmental education, eco-creative pedagogies seek to establish collaborative networks among educators, schools, eco-artists, environmental activists, non-governmental organizations, and think tanks (University of Northampton *et. al.,* 2025).

2. Improving Ecological Consciousness and Green Skills: By incorporating sustainable practices into curricula, these strategies raise ecological consciousness and improve green skills in education. Additionally, they aid in the creation of an educational framework that is sensitive to cultural differences (University of Northampton *et. al.,* 2025). Building climate resilience can be achieved through co-designing resources such as children's comic books and integrating green skills into school curricula through the implementation of training programs. A broad audience can access training provided by teacher networks (University of Northampton *et. al.,* 2025).

3. Teacher Training and Resource Development: Implementing training programs can integrate green skills into school curricula and co-design resources like children's comic books to build climate resilience. A broad audience can access training provided by teacher networks (University of Northampton *et al.,* 2025).

4. Long-Term Social Impact: By strengthening international partnerships in environmental education and expanding the integration of critical environmental competencies into civil society, these programs prepare the next generation of educators to be resilient to climate crises.3. Place-based pedagogies guarantee that learning directly improves natural environments and communities (University of Northampton *et. al.,* 2025).

5. Developing a Mindset and Sustainability Competencies: Green Pedagogy provides an organized method for lesson planning that incorporates sustainability competencies into academic or professional domains. To promote fresh, more sustainable viewpoints, it plays on learners' emotions

and reveals their values. Two pedagogies that align with Education for Sustainable Development (ESD) are case studies and project-based learning. Students apply what they have learned. To promote empowerment and personal development over hopelessness, students apply what they have learned to their immediate surroundings while considering the wider ramifications of their actions. By automating sustainable responses and displaying sustainability values for everyday problem-solving, it fosters a sustainable mindset. The objective is to go beyond the shallow level of understanding and aim for the development of deep-seated perspectives (Fox &Wogowitsch, 2021).

6. Promoting Environmental Awareness and Language Skills: In countries like Bangladesh, English lessons focusing on environmental awareness often led scholars to play life-changing functions in environmental protection. This act simultaneously improves English language skills and consolidates environmental awareness. Environmental education is seen as a significant force for societal prosperity, inspiring dutifulness and commitment. Green teaching in classrooms involves students and teachers in preserving the atmosphere. EFL practitioners can contribute to sustainable development through green pedagogy, encouraging eco-friendly actions in daily life and institutions (Hossain, 2019).

Conclusion

In conclusion, addressing the blended crises of biodiversity loss and climate change requires a radical shift in biology teacher education. Traditional models of education focusing on content delivery and standardized testing, updated not unverifiable, are not enough to prepare future biology teachers to address these global emergencies. Eco-pedagogy helps to prepare future generations that are conscious of their environment. Environmental degradation comes with socio-political drivers; an eco-pedagogy perspective inspires a deeper connection between humans and the natural world. At the same time, while green technologies offer concrete, practical solutions connecting education with sustainable development goals. Both approaches provide agents' for addressing a more expansive conception of biology education that nurtures ecological literacy, critical thinking and meaningful action towards sustainability challenges. For biology teachers to meaningfully inspire and navigate the challenges of the 21st century with their students their education must enable skills appropriate for and active participation in curricula, instruction and the wider community. Ultimately, transforming biology teacher education through eco-pedagogy and green technologies are important in helping develop environmental mindfulness and motivation to protect our planet's future.

Recommendations

To effect this transformation in biology teacher education, the following

recommendations are advanced:

1. Adopt UNESCO's Greening Curriculum Framework: Teacher education institutions ought to implement UNESCO's ten-step framework where emphasis is placed on needs analysis and stakeholder engagement plus pilot initiatives accompanied by continuous staff development to build sustainability curricula responding to local contexts.

2. Raise Project-Based and Inquiry-Based Learning (PBL/IBL): This should be by way of the methodologies used in teaching, which allows for experience-based learning, critical inquiry, and student-centered exploration of real-world sustainability challenges.

3. Practically insert Green Technologies: Biology teacher preparation programs shall include practical engagements with actual tools for renewable energy, agroecological practice, and circular economic concepts as a bridge from theoretical knowledge to innovative technological solutions.

4. Build Transdisciplinary Collaboration: A course should encourage cooperation among different fields as a reflection of the interconnecting nature of environmental and social matters. This prepares teachers for dealing with sustainability from an integrated perspective.

5. Make resources available in developing environments by investing in green technologies and materials. Governments, NGOs, and educational stakeholders should ensure inclusive access particularly in resource-limited institutions so that educational inequalities are not increased.

6. Partnerships with communities should be built. A biology educator program should make it a point to encourage community involvement so that future biology educators can relate classroom lessons to ecological needs and sustainability practices in the communities.

7. Put in Eco-Pedagogy and Critical Consciousness Principles: Apart from getting to know facts, trainers should learn how to build up a sharp awareness of the political-economic sides of environmental issues in their learners thus making them active doers of ecological justice and planet care.

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